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THE LAFAYETTE RADIO STATION AND ITS RELATION TO THE UNITED STATES NAVAL COMMUNICATION SERVICE AND THE WORLD WAR.

By Commander Stanford C. Hooper, U. S. N., Member.

It was only approximately twenty-five years ago that news items first appeared in the public press relating that an Italian, Marconi by name, had successfully demonstrated an invention of his whereby messages had been transmitted and received between distant points considerably beyond the range of visibility without the use of connecting wires—had, in fact, communicated through space by means of a system of "wireless telegraphy."

Although various remarkable discoveries in the realm of science were being made and demonstrated, the reports concerning the practicable demonstration of a method of wireless

telegraphy were received with some skepticism by the public generally, as the only means of rapid signaling between distant points then known, namely, the land line telegraph and ocean cable systems, could not function without the use of connecting wires, and it was generally believed to be impossible to exchange rapid communications between points separated by distances of the order of 50 or 100 miles without utilizing connecting wires.

It was manifest to all, however, that should it be possible to develop a method of signaling which did not require the use of connecting wires, rapid communication could be had with ships at sea—and between ships at sea—with the resulting enormous possibilities from a humanitarian and military point of view, and therefore the reported demonstration of Signor Marconi was a matter of great curiosity and interest to the Navy and the subsequent reports relating to this achievement were closely followed.

The fact that the system was practicable and applicable to sea-going ships having been eventually established to the satisfaction of the Naval authorities, steps were taken to apply it to the Naval service both on shipboard and on shore, and from this beginning, which was modest indeed, the progress of development of the art of "wireless" or radio signaling has been consistently advanced by the Navy, culminating for the time being, in the achievement of having successfully completed, as a war measure, the great Lafayette super-high power station in France, the most powerful radio station in the world, and whose test signals beginning on August 21st, 1920, consisting of the word "LAFAYETTE" repeated over and over again, being spelled out by the usual combinations of dots and dashes comprising the alphabet of the International Morse telegraph code, spanned the entire globe.

To the United States Navy then belongs the distinction of having first constructed a radio station capable of communicating all over the world.

General Pershing, in the name of the United States Army, spoke to the French Army and nation at the tomb of Lafayette in Paris and his words, in all likelihood, will be transcribed in history for the perusal of future generations.

The Lafayette radio station, located at the small village of Croix d'Hins, 16 miles from Bordeaux, began speaking on August 21st, 1920, as a virile living testimonial of the United States Navy, not only to France but to the peoples of all lands, to aircraft in flight among the clouds and to ships on all the seas, and this station will, without doubt, continue so to speak to future generations.

An interesting coincidence in connection with the beginning of the tests of the Lafayette station is that a statue of General Lafayette, which had been presented to France by America, was unveiled at Metz by Marshal Foch on August 21st, 1920, or the date on which these tests began.

WIRELESS OR RADIO CHARACTERISTICS.

Before proceeding with a discussion of the events which led up to the establishment of the Lafayette radio station, the magnitude of the work involved in its establishment, the general description of the station and its relation to the Navy and to the World War, it may be well to discuss briefly and in general terms, the comparatively new but highly technical radio art, whose development is still in its infancy, and also some of the principal difficulties encountered when utilizing this medium of communication.

Electricity as force or power is today in universal use throughout the world and the peoples of all civilized lands are more or less familiar in a general way with this force, at least with its manifestations.

Electric lights in homes and places of assembly; on the streets of towns and cities; on automobiles; electric street car and interurban transportation; the clicking of telegraph instruments in railroad and commercial telegraph offices; the

human voice in the telephone instruments, are some of the more commonplace manifestations, and these manifestations are all the result of electric or electro-magnetic forces, or combinations of these forces with other forces.

Radio communication is also the resultant of electro-magnetic forces, but of inherently widely different characteristics from similar forces used for ordinary purposes.

The principal distinction between electric or electro-magnetic forces used for ordinary purposes and the electro-magnetic forces used in radio, and the distinction which stands out most prominently and can be more generally understood, is that for ordinary purposes these forces cannot be utilized and the systems will not function unless a complete metallic path, consisting of copper wires or other electric conductors, or a complete path formed partly by metallic conductors and partly by the earth, is provided for the flow of the electric current from its source to the points at which the manifestations take place and back again to its source; whereas for radio purposes no such path is required, the atmosphere or the "ether" being the only connecting medium required between radio stations.

To the casual reader it may be inexplicable, for example, how a radio station on a ship which is far out at sea and separated, say, 500 miles from another ship at sea equipped with radio apparatus, and also separated, say, 500 miles from a land radio station situated on the nearest coast, can, by merely causing an electric current to flow in the antenna which is stretched between the ship's masts, send messages to the ship or shore station, or to both simultaneously, and by disconnecting the radio transmitting equipment and connecting the receiving apparatus to the same antenna, receive acknowledgments for the messages sent, or receive other messages in turn.

It is obvious that a considerable amount of energy must necessarily be given off by the ship's antenna to cause even the most feeble manifestations to take place at other radio

stations 500 miles away. Nevertheless these manifestations take place in the form of movements of the diaphragms of the operator's head phones and cause sound of sufficient intensity to enable the operator to easily recognize the combinations of dots and dashes comprising the alphabet of the International Morse telegraph code in which radio signals are sent.

To persons in the immediate vicinity of radio stations when transmitting messages, as on shipboard, no apparent change in the surrounding conditions can be detected while the ship's antenna is giving off energy, and as a matter of fact no one on board ship, other than the radio operator may be aware of the fact that the transmitter is functioning.

It may be asked—what is this force, which is not visible and cannot be physically grasped, but which is sufficient to cause the diaphragms in the operator's head phones at distant stations to vibrate in response to radio signals sent out by a transmitting station—and what is the nature of the intervening medium by which this force is propagated or conducted through space?

The answer is, in accordance with the accepted theory, that the earth is immersed in an illimitable ocean of ether, just as fishes are in water, that the ether is an almost infinitely elastic, infinitely tenuous substance which surrounds and permeates all matter and all space, that the ether is normally at rest with respect to all moving bodies and all other substances and that the only force which can disturb and set in motion the ether, is the production of an electrical discharge in it, and that by producing these electrical discharges, electro-magnetic or ether waves are created which possess electro-magnetic energy and which travel outward and away from the point of disturbance to all points of the compass with the speed of light, or at the rate of 300,000,000 meters or 186,000 miles per second, and that as these waves sweep across the wires of an antenna in their path, some of the electro-magnetic energy contained in the waves is given up by inducing or creating feeble electric currents which flow in the antenna, these

induced currents in turn creating sufficient magnetic force in the receiving apparatus to actuate the diaphragms of the operator's head phones.

Since, according to theory, the only connecting medium between radio stations is the ether, which surrounds and permeates the entire globe, it would appear at first hand that all that would be necessary to inaugurate and maintain radio communication service would be the establishment and operation of the required stations.

It is after the stations have been established and placed in operation, however, that the difficulties of operation manifest themselves, as the operators at the various stations will attest; those who serve their own and sister ships' passengers and crews, while at sea, by constantly "exploring the ether" for messages or distress signals, by means of their receiving apparatus; those in the trans-ocean stations on shore endeavoring to carry on communications, and the many thousands of amateur operators who have their stations scattered all over the United States and other parts of the world, and who communicate with one another within the transmitting ranges of their stations, or "listen in" for the signals of the more powerful stations.

INTERFERENCE BETWEEN RADIO STATIONS.

The transmitting apparatus at radio transmitting stations is adjustable to from one to as many as 15 different "wave lengths" or "ether routes through space," so to speak. These waves may be as low as 100 meters and as high as 25,000 meters in length, depending on the design and arrangement of the equipment for the service in which the stations are to be used. Radio receivers now in use are readily adjustable to any wave lengths from 100 to 30,000 meters.

A wave length, in radio technique, is defined as the distance through space traveled by the wave or electro-magnetic oscillation, during one complete oscillation or cycle in the electrical circuit producing the wave.

For example, a transmitting station in operation using a wave length of 1,000 meters indicates that the antenna circuit, in conjunction with the arrangement of the circuits of the transmitting apparatus, is so arranged that the electrical length of the circuit is such as to require a period of time of one three hundred thousandth of a second for the electric current to flow from its source, through the various circuits and back to its source, reverse its direction and again flow from its source, through the various circuits and again back to its source, in other words, completing one electrical oscillation or cycle, the rate of speed of flow for an electric current being given as 300,000,000 meters per second. During this oscillatory period the ether wave will have traveled away from the station a distance of 1,000 meters and during one second will have traveled 300,000,000 meters or 186,000 miles. These waves, therefore, will spread over the earth from the point of disturbance and travel completely around the globe a number of times during one second of time.

If, at a receiving station, the receiving equipment is adjusted corresponding to a wave length of 1,000 meters and if the transmitted signal is sufficiently powerful, the receiving equipment will respond to the transmitted signal.

In the present stage of the radio art it usually is not feasible to adjust the transmitting apparatus to an exact wave length without causing the energy contained in the ether wave to "splash over," so to speak, on either side of the basic wave and as a result comparatively "broad" waves are transmitted by many radio stations and invariably two or more transmitting stations of approximately equal power, located within a few hundred miles of each other and functioning simultaneously on the same or nearly the same wave lengths, will interfere with one another within their effective transmitting ranges, that is to say, the operators at receiving stations will usually be unable to distinguish the signals of any one through the interfering signals of the others.

Radio stations are now becoming so numerous that endeavors are being made to limit this splashing over effect so that wave lengths of the different classes of stations may be separated by only a few meters, and at the same time prevent stations in the same general locality from interfering with one another, to the end that the different classes of stations may operate simultaneously and still get their traffic through.

In the present stage of the radio art the shortest wave length which can be advantageously used by transmitting stations corresponds to about 100 meters in length and the longest to about 25,000 meters. The longest wave length actually employed at the present time, namely, 23,450 meters, is in use at the Lafayette radio station.

The shortest wave lengths are used by aircraft with their very small antennas and are effective for only comparatively short distances, the medium length waves by ship and coastal stations and are effective for distances of the order of 500 or 2,000 miles, and the longest waves by the super-high power trans-ocean stations with their immense antenna systems supported at great heights by self-supporting steel towers or guyed masts and are effective up to distances of not less than 12,000 miles in all directions from the transmitting station.

Owing to the so-called "splashing over" of the energy contained in ether waves produced by radio apparatus in the present stage of development of the radio art, less than 300 waves of different lengths or "ether routes," so to speak, can be utilized for practical communication purposes, notwithstanding the many thousands of radio stations of all classes in existence throughout the world.

This feature possessed no disquieting aspects so long as the maximum effective transmitting ranges of stations did not exceed distances of the order of 2,500 miles, as the number of stations having such ranges on shipboard and within the boundaries of the different countries could be controlled, and widely different wave lengths could be used and suitably timed

transmitting schedules could be adopted, to avoid undue interference between stations.

With the development of stations, similar to the Lafayette station, having effective world-wide transmitting ranges, however, this aspect of the situation assumes serious proportions as the only means of preventing interference between a number of such stations situated throughout the world is by suitable separation of wave lengths, and the number of such stations which may be established and successfully operated, depends on the number of wave lengths available for international assignment within the long wave length band after providing for the required separation between wave lengths in this band.

The prevention of interference between stations, particularly as regards the super-high power stations, therefore, by the development of improved radio equipment which will radiate energy only on the exact wave length to which it is adjusted, and eliminating the so-called splashing over of the waves under any conditions, is one of the problems yet to be solved by the radio engineer.

INTERFERENCE FROM STATIC.

Another difficult problem which is awaiting solution by the radio engineer and the one which has been and is now of primary importance to the radio service is the elimination of the effects of "static" on the radio apparatus at receiving stations.

Static, or electrical disturbances in the ether, caused by electrical discharges between nearby clouds during thunder storms, by electrical discharges from clouds to the earth, and by other causes which are not as yet generally understood, are a veritable nightmare to the radio operating personnel, as these discharges also set in motion ether waves of varying lengths and cause the radio receiving apparatus within their effective range to respond with varying degrees of intensities, thereby creating exceedingly troublesome interference, which

may prevent, at times, the receiving operator from distinguishing the signals sent out by a distant station which he may be endeavoring to copy.

Static disturbances vary in quantity, quality and intensity over a very wide range with respect to their frequency, wave lengths, and loudness of response in the operator's head phones; also with respect to the seasons, to various localities, and to the daylight and dark hours.

For example, these disturbances are much more prevalent in the tropics than in more northern areas during the same seasons of the year; they vary in intensities during different periods of the day and night, and when static is prevalent, the radio receivers will usually respond to it at practically equal intensities over the entire range of the instrument, regardless of the wave lengths to which they may be adjusted. During certain periods of the year and in various localities, particularly in the tropics, static may become so severe as to cause a continuous roar with intermittent crashes of sound of still greater intensity in the operator's head phones for hours or possibly several days at a time and during such "static storms" as they are called, it is usually impossible for an operator to distinguish other than very loud radio signals.

Static disturbances begin to manifest themselves during the spring months, become more frequent and intense during the summer months and disappear in the fall.

As a rule there is experienced very little interference from static during the winter months and it is during this season that carrying on communication by radio is a pleasure rather than a hardship to the operating personnel.

To give a broad illustration of the exceedingly troublesome interference caused the radio operators by vagrant ether waves, or static, this source of interference may be compared to an intruder tapping a telephone line over which a conversation is taking place, and insisting on speaking over the line during the conversation, either at intermittent periods or continuously

and with varying degrees of loudness from whispering to shouting.

This comparison may also be used to illustrate the effects of interference between radio stations themselves which may be situated within the effective range of each other's transmitters when the transmitters are adjusted to the same or nearly the same wave lengths.

An operator on a ship at sea, for example, who may be copying a message from another ship or shore station on the commercial wave length of 600 meters, can never tell when other ship or shore stations within the effective range of his receiving apparatus may start transmitting on this same wave length.

As practically all commercial ship radio traffic is now transmitted on a wave length of 600 meters and as thousands of sea-going vessels are now equipped with radio, interference between stations is the rule rather than the exception and results in endless repetition of radio messages or parts of messages from this cause alone.

Radio operators must remain on duty in their receiving stations and wear their head phones when heavy static is prevalent as well as at other times. The only exception to this rule is that when electrical or thunder storms are in progress in the vicinity of the station. At such times the receiving apparatus is disconnected from the antenna and the latter connected directly to the earth. On board ship the antenna is connected to the hull of the ship which in turn makes electrical contact with the sea. If electrical charges collect on an antenna during a storm, or if the antenna should be struck by lightning, the charge will be carried direct to the earth without injury to the operator or damage to the equipment providing the antenna has been grounded. After an operator has been on duty at a busy radio station for from four to eight hours at a stretch, contending with interference between stations and from static, he is usually exhausted physically from the mental nervous strain he has undergone.

It is likely that, as a general rule, passengers on the palatial ocean liners, for example, give little or no thought to the comparatively few radio operators on board, some one of whom is always on duty in the radio room both day and night and patiently performing his duties, sometimes laboring under very great difficulties known only to himself and to his fellow operators.

Various devices have been developed which have the effect of considerably reducing the effects of static and interference between stations but these effects still constitute the only remaining serious obstacles to satisfactory world-wide communication service by radio.

ENERGY LOSSES IN ETHER WAVES.

Unlike the land line telegraph and cable signals whose electrical energy is controlled and guided by the individual metal conductors physically connecting the various stations, the electro-magnetic energy, by the utilization of which radio signaling is made possible, is discharged into the atmosphere at the transmitting station and this electro-magnetic energy travels away from the station to all points of the compass in the form of ether waves.

These waves have no limits as regards the distance traveled through space, but the energy contained in the waves decreases with the square of the distance. While the basic limitation as regards decrease in energy of ether waves with the distance is of general application, the effects as regards actual energy dissipation vary in different localities, with different seasons of the year, and finally with respect to the daylight and dark hours in all areas.

Ether waves retain a greater relative percentage of energy while traveling through space over some areas as compared to others. For example, they suffer less dissipation or absorption of energy when traveling over salt water than over fresh water, when traveling over fresh water than over land, when travel-

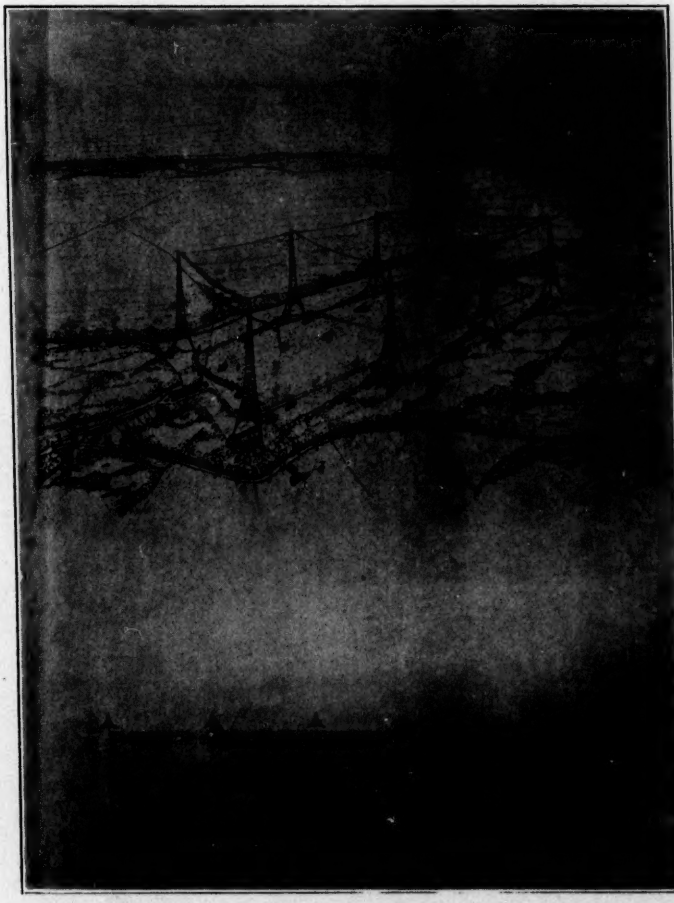


FIG. 1.—GRAPHICAL PLAN OF THE COMPLETED STATION, SHOWING THE RELATIVE PROPORTIONS OF THE RADIO OPERATING BUILDING, THE EIGHT IMMENSE SELF-SUPPORTING STEEL TOWERS, AND THE ANTENNA SYSTEM SUSPENDED FROM THE TOPS OF THESE TOWERS.

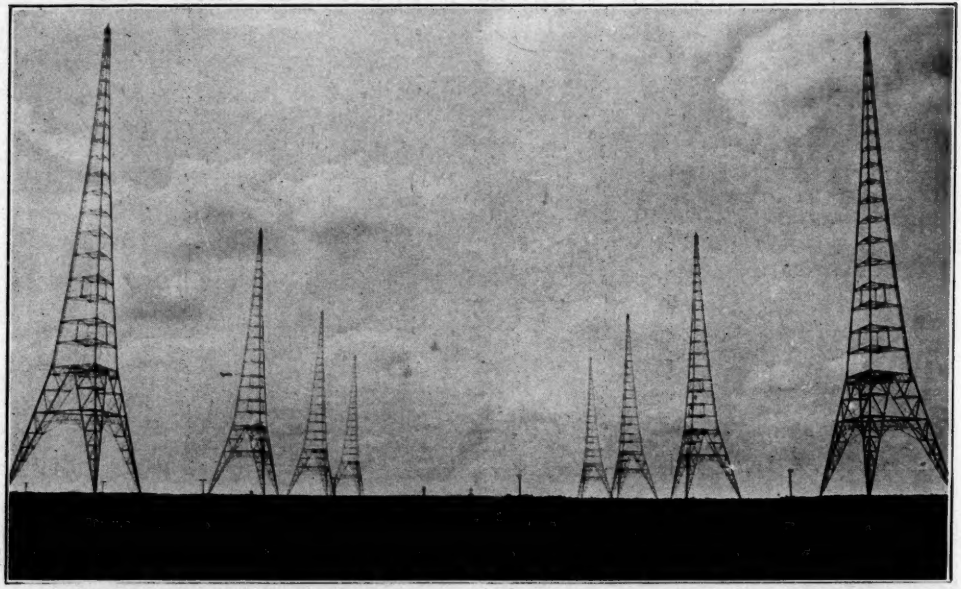


FIG. 2.—BIRD'S-EYE VIEW OF THE LAFAYETTE SUPER-HIGH POWER RADIO STATION, SHOWING THE EIGHT 820-FOOT SELF-SUPPORTING STEEL TOWERS SUPPORTING THE ANTENNA AND THE RADIO OPERATING BUILDING IN THE DISTANCE.

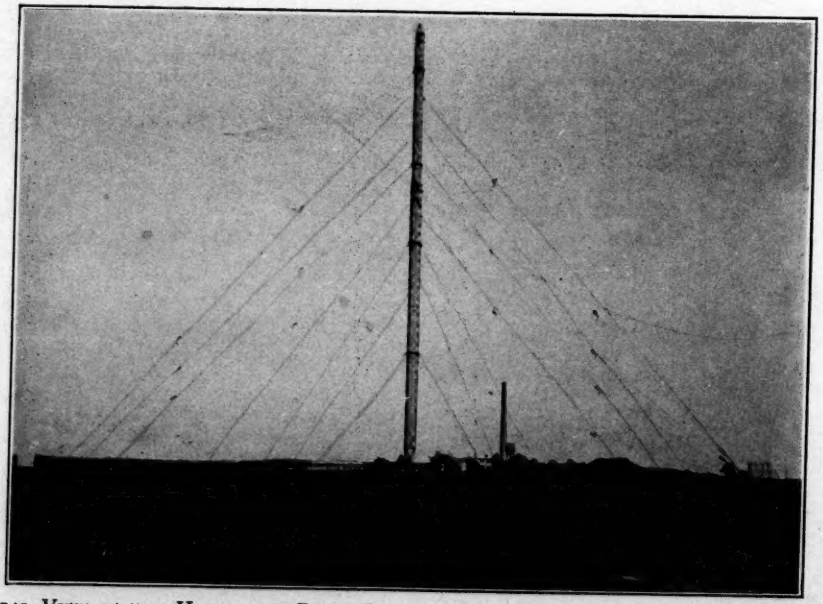


FIG. 3.—GENERAL VIEW OF THE HIGH-POWER RADIO STATION ESTABLISHED BY THE GERMANS AT TUCKERTON, N. J. THIS STATION, WHICH WAS BUILT TO COMMUNICATE ACROSS THE ATLANTIC, CONSISTS OF ONLY ONE ANTENNA SUPPORT—A STEEL LATTICE GUYED MAST 865 FEET IN HEIGHT—FROM WHICH AN "UMBRELLA" TYPE ANTENNA IS SUSPENDED. THIS STATION FORMS A STRIKING CONTRAST TO THE LAFAYETTE STATION, WHICH WAS BUILT TO ABSOLUTELY INSURE COMMUNICATIONS ACROSS THE ATLANTIC.

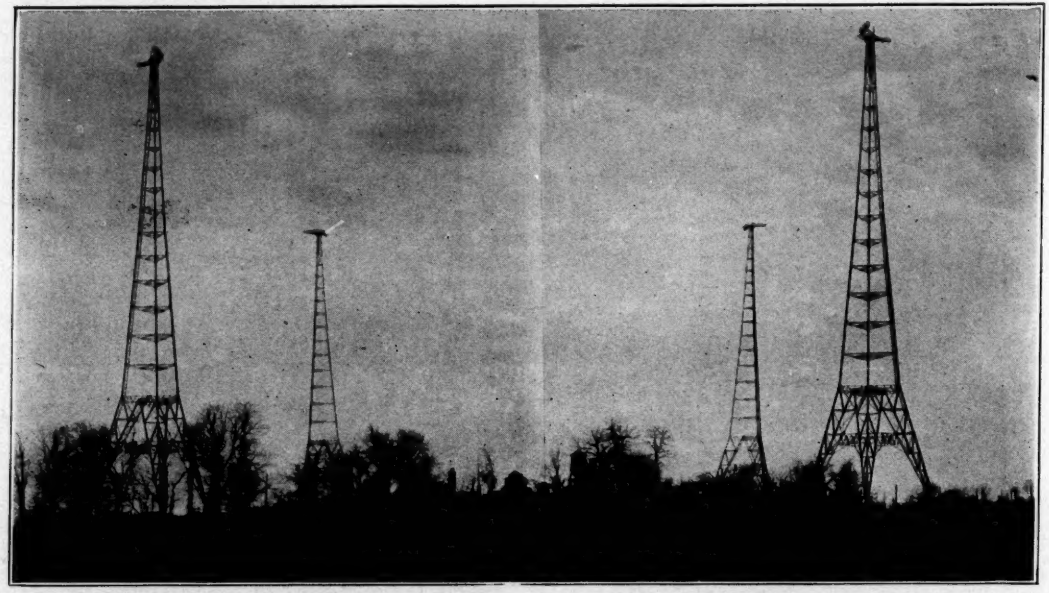


FIG. 4.—GENERAL VIEW OF THE ANNAPOLIS 500-KILOWATT STATION, WHICH WAS ESTABLISHED TO MAKE CERTAIN THAT COMMUNICATIONS FROM THE UNITED STATES TO OUR EXPEDITIONARY FORCES IN FRANCE WOULD BE MAINTAINED INDEPENDENTLY OF THE CABLES, IF NECESSARY.

ing over comparatively flat country than over mountainous or relatively uneven country, when traveling over areas north of the equator than over similar areas south of the equator. A radio station which has an effective communicating range of say only 500 miles during the spring, summer and fall months may have no difficulty whatever in working over distances of 1,000 or 1,500 miles during the winter months.

The signals from certain radio transmitting stations may be copied with ease at a receiving station at night although the signals from the same transmitting stations may be inaudible during the daylight hours. An operator on a ship in mid-Atlantic at night during the winter months can readily distinguish signals from medium power coastal stations in the United States, France, Germany, Italy, the British Isles, Spain and Africa in turn, although, during the daylight hours, in the summer months, he might not at times be able to hear signals from even high power stations, other than super-high power stations such as the Lafayette station, located in any of these countries.

It will be evident from the foregoing that to insure facilities for reliable and continuous transatlantic communications by radio between our forces in France and the United States Government, during the daylight and dark hours of every day in the year, would likely result in the establishment of a station sufficiently powerful to readily communicate around the world during the winter months, particularly during the hours between sunset and sunrise.

CONCEPTION OF THE LAFAYETTE RADIO STATION.

The responsibility for insuring satisfactory communication service with our Atlantic, Pacific and Asiatic Fleets and their auxiliaries, devolves on the officers of the Naval Communication Service, therefore upon our entrance into the World War, Europe being the battleground, our immediate and primary responsibility was to see to it that satisfactory service was provided for our forces in the Atlantic.

High power radio stations were available on our Atlantic coast which could be utilized to insure adequate and satisfactory service to our ships crossing the North Atlantic until they should come within communicating range of the high power stations of the Associated Powers on the European side, and the transatlantic cables were available to augment this service.

These stations were the former German stations at Sayville, N. Y., and Tuckerton, N. J., and the Marconi Company's stations at New Brunswick, N. J., and Marion, Mass. The Naval station at Arlington, Va., just outside of Washington, was also available. Several medium and low power stations were located along our Atlantic coast and were also available for other than long distance work.

All ships of the Navy, from tugs to battleships, had long been equipped with radio, therefore contact could be had through the shore stations and satisfactory service with our forces in the Atlantic was assured.

The Sayville station was established by German interests during the year 1912 and was used to communicate with a similar station at Nauen in Germany. The maximum effective power of this station did not exceed one hundred kilowatts and it was found to be entirely inadequate in power to render service with Germany at other than intermittent periods, when heavy static was not prevalent.

Nevertheless this station proved to be of incalculable value to the Germans after the outbreak of war in 1914, as the German transatlantic cables were promptly cut by the Allied Powers and the only means of transatlantic communication service remaining to the Central Powers was through the Sayville station.

Under the exigencies of the situation, abnormally large volumes of traffic passed through this station, but, of course, it was woefully inadequate to meet the full demands made upon it and it was often virtually inoperative for transatlantic service due to interference from static.

Officers of the Naval Communication Service had been detailed to this station as censors upon the outbreak of war, and later on—but while our country was still maintaining neutrality—the German operating personnel were replaced by operators of the Naval Communication Service.

The Tuckerton station was under construction by German interests when the war broke out but was rushed to completion and placed in service. The effective power of this station was somewhat less than the Sayville station, but it handled some transatlantic traffic with a station at Hanover in Germany and also with the Nauen station. The Tuckerton station was also taken over for operation by Naval personnel at the same time as the Sayville station.

The New Brunswick station was established by the Marconi Wireless Telegraph Company of America, which company was then controlled by the British Marconi Company, for communicating with a similar station at Carnarvon, Wales. This station had been completed just prior to the beginning of hostilities in Europe, but it was found to be entirely unreliable and unsatisfactory for the purposes intended. As a result of limitations placed on the Carnarvon station by the British authorities upon the outbreak of war, the New Brunswick station would have been obliged to remain inoperative in any event and extensive experimental and development work was therefore undertaken at New Brunswick to improve the station. As a result of this experimental and development work a new type of radio transmitter was produced by the radio engineers of the General Electric Company known as the Alexanderson Alternator and one of these units, of 200 kilowatt power capacity, was installed in the station under the auspices of the Naval Communication Service after the station had been taken over for operation as a war measure.

The New Brunswick station rendered most valuable services to the Navy and the Government during the war, this station being eventually used to transmit, to the Nauen station, the

correspondence from the United States Government to the German Government which led up to the Armistice.

The Marion station had not yet been completed when the United States entered the war and when finally completed it was found entirely unsuitable for transatlantic work. This station had not yet been placed in an operative condition at the time of the signing of the Armistice and therefore it rendered no service to the Navy, but adequate service proved to be available without this station.

In order to improve the operation of the Sayville and Tuckerton stations for war purposes the German apparatus was ordered replaced by Navy standard transmitters of the Poulsen-Federal type, a 200-kilowatt transmitter being ordered installed at Sayville and a 100-kilowatt transmitter at Tuckerton.

Similar equipment of from 200 kilowatts to 350 kilowatts power capacity had previously been installed in the stations of the Naval transpacific high power radio circuit at San Diego, Calif.; Pearl Harbor, Hawaii, and Cavite, Philippine Islands, and had given satisfactory service for distances of from 2,500 to 5,000 miles across the Pacific.

With the improved New Brunswick, Sayville and Tuckerton stations not only was reliable and adequate service assured to our ships in any part of the North Atlantic, but these three stations would also be available to render transatlantic service with suitably equipped stations in Europe, under any but the worst atmospheric or static conditions, and they could, therefore, be used to augment the transatlantic cable service.

It was becoming apparent that the transatlantic cables were loaded to their full traffic capacity and it was obvious that in order to take care of the prospective enormously increased volume of transatlantic communications, occasioned by the presence of large bodies of our troops in France, recourse would have to be had to radio.

Moreover it was felt in the Navy Department that there was grave danger of the cables being cut by German submarines, in which event the only means of maintaining con-

tact with our Expeditionary Forces in France and exchanging vital communications would be by radio.

The French were endeavoring to increase the effective power of their Eiffel Tower station in Paris and they began the construction of a new station at Lyons for communicating with the United States. The Italians began the construction of a station near Rome for the same purpose and the English were endeavoring to improve their Carnarvon station with the same end in view. The existing or projected European stations and those on our Atlantic coast, however, did not exceed 250 kilowatts power capacity, and while these stations could be relied upon to give satisfactory transatlantic service when heavy static was not prevalent, they could not be expected to give continuous efficient service, particularly during the summer months when interference from static is at its maximum.

After careful study had been given to the situation in collaboration with the Allies, and having in mind the possibility of some or all of the cables being cut by submarines, the Navy Department decided to establish a super-high power station of 500 kilowatt power capacity at Annapolis, Md., to make certain that facilities would be available to transmit communications to our Expeditionary Forces in France at all times and independently of the cable systems if necessary, and the Department advocated the construction of a similar station in France, but of twice this power, or 1,000 kilowatt capacity, to insure communications from France to the United States.

Static and other atmospheric conditions unfavorable to the reception of radio signals are much more severe along the Atlantic coast of the United States than they are in Europe, therefore a much more powerful transmitting station would be required to transmit more powerful signals across the Atlantic to insure their reception in the United States than would be the case for signals transmitted from this country for reception in Europe.

It was planned to remotely control the Annapolis station from the Navy Department in Washington for duplex opera-

tion; in other words, to give the control of the transmitting equipment, for signaling, to operators located in the receiving station in the Department, thereby enabling messages to be received from European stations at the same time messages were being transmitted to Europe from the Annapolis station.

The transmitting equipment at radio transmitting stations can readily be controlled, for signaling, from a remote control and receiving station located several miles away, by connecting the two stations with a land line telegraph wire circuit and causing electric currents to traverse this circuit. These electric currents energize electro-magnets at the transmitting station, the electro-magnets in turn alternately closing and opening the key contacts in the signaling system, this closing and opening of the key contacts in the signaling system corresponding to the dots and dashes made by the operator on his transmitting key at the remote control station.

By locating a remote control and receiving station for high power radio transmitting stations twelve or more miles distant from the transmitting station, and if modern radio receiving equipment is used, an operator can receive weak signals from a distant station on a wave length of say 10,000 meters while another operator is sending signals from the nearby transmitting station on a wave length of say 15,000 meters. The distance between Annapolis and Washington being approximately 40 miles in an air line, duplex operation could be relied upon for satisfactory service.

The question of radio communications as they affected the allied and associated powers had long been under consideration by an Inter-Allied Radio Commission in Paris, but a decision with respect to the establishment of an extra powerful station in France for communicating with the United States had not as yet been decided, when on November 28, 1917, a cablegram was received in the War Department from General Pershing containing urgent recommendations that steps be taken immediately in preparation for handling cable traffic by radio.

No specific recommendations were made in this cablegram concerning improvements to existing high power stations or the establishing of additional super-high power stations either in France or in the United States, as these were details to be taken care of by our Government.

The cablegram from General Pershing supported the contentions of the Navy Department that there was grave danger of the cables being cut, which view, up to this time, apparently was not shared by all of the associated governments, although they were preparing to augment the transatlantic cable service to some extent by the establishment of high power radio stations.

Correspondence which later reached the Navy Department disclosed the anxiety shared by our officers in France concerning the possibility of interrupted communication with our Government. A letter written in Paris by General Russell to General Pershing dated August 23rd, 1917, reflects the anxiety felt in this regard in the following words:

"There is no question of the grave situation in which we may find ourselves as a result of extensive cable cutting, which, in the belief of all cable authorities I have consulted, may be easily effected by the enemy. The enormous importance of immediate provision of reliable extensive transatlantic radio telegraphic service is therefore evident."

Upon receipt of General Pershing's cablegram of November 28, 1917, a conference between communication representatives of the Army and Navy was immediately called to consider the situation and met at New London, Conn., on December 4, 1917, and again at Washington on December 12, 1917. Representatives of the associated powers were present at these conferences and they were therefore of the nature of inter-allied communication conferences to collaborate with and advise the Inter-Allied Radio Commission in Paris which Commission was then holding frequent sessions to study and examine into conditions affecting radio communication throughout the world.

As a result of the deliberations of the conferences held at New London and Washington, it was decided to expedite the improvements which were under way at the Sayville, Tuckerton and New Brunswick stations, to remotely control these stations by land line connections from a central control station for simultaneous transmission and reception, to establish additional receiving stations in localities where the electrical conditions appeared to be favorable to assist in the reception of signals from existing and projected European stations, to rush the completion of the Annapolis station with its remote control facilities from Washington, to investigate the question of possibly establishing a still more powerful station than the projected Annapolis station in one of our southern states along the Atlantic seaboard where sleet and ice formations were not likely to occur during the winter months, thereby endangering the continuous operation of the station by the collapse of the antenna system in winter, to urge the expeditious completion of improvements to existing stations in allied countries and the completion of the projected new stations, and finally, to insist on the immediate construction of a station in southwestern France of not less than 1,000 kilowatt power capacity to insure continuous communication with the United States.

Repeated recommendations had previously been made by the Navy Department that a super-high power radio station be established in France for communicating with the United States, but as yet no definite information had been made available as to what measures were contemplated in this respect.

M. Tardieu, French High Commissioner in the United States, on October 29, 1917, reflected the Department's attitude in this respect in the following quoted cablegram to his government:

"The American Navy considers as very important the question relative to the construction of a new very powerful radio station. It requests to be informed without delay if it be

decided to construct such a station. It promises all necessary assistance so far as concerns the rapid supply of American material which would be required."

This cablegram was followed by another from the Secretary of the Navy to the United States Naval Attaché at Paris under date of October 31, 1917, as follows:

"Request immediately full information relative to action being taken in France to establish new extra powerful radio telegraphic station. If material from the United States is necessary, inform us immediately."

Information had previously been made available to the French authorities that the Navy was prepared to obtain and furnish arc radio transmitters of as high as 1,200 kilowatt power capacity, self-supporting steel radio towers of not less than 800 feet in height, and also to undertake the establishment and operation of an extra powerful station in France if so desired.

The Navy Department realizing the necessity of absolutely insuring the maintaining of facilities for the exchange of rapid communications between France and the United States was impressed with the gravity of the situation which would confront our Government, if, after transporting a huge army to France, communication with these forces should be interrupted, owing to the failure of the ordinary channels of communication, and contact with our troops should be lost for comparatively long periods of time. The Department's recommendations concerning the extra powerful radio station in France were made with the view to making this contingency as remote as it was possible so to do. Plans had been completed for the extra powerful station to be established at Monroe, North Carolina, and work on this station was about to begin when the Armistice was signed, whereupon all activities in this connection were abandoned.

As a result of the recommendations made by the United States Government following the radio conferences at New London and Washington, it was decided by the Inter-Allied

Commission in Paris to establish an extra powerful radio station in France, the station to be of 1,000 kilowatt power capacity.

It was freely admitted by the French Government, however, that, owing to the conditions in France, the necessity of turning all creative energy into the manufacture of supplies for the Army and the dearth of skilled labor, it would be impracticable for them to furnish skilled labor or material except for the construction of the concrete foundations for the radio towers and for the construction of the radio buildings. It was agreed, therefore, that the French would construct the tower foundations and buildings, the United States to furnish and erect the towers and antenna system, also furnish and install the 1,000-kilowatt radio transmitters with all accessories complete in duplicate throughout. In the United States it was agreed between the War and Navy Departments that, as the Navy had had extensive experience in the design, construction and operation of high power radio stations, the Navy would take full charge of the establishment of the station.

The Annapolis station, which was to consist among other major items, of 4 self-supporting 600-foot steel towers as antenna supports and duplicate 500 kilowatt radio transmitters, represented the most powerful radio station project yet undertaken in the world, and a heavy drain had already been made on the qualified personnel available to the Navy to undertake this work, leaving only a skeleton force from which to build up a working force to undertake the construction of the station in France which work was to be of still greater magnitude, as the station in France was to consist of 8 self-supporting 820-foot steel towers and duplicate 1,000-kilowatt radio transmitters.

Qualified personnel was made available, however, and a force of more than 600 skilled workmen, including steel workers, bridgemen, electricians, etc., was quickly gotten together and sent to France, the first unit of this force arriving at Bordeaux in the early spring of 1918. This force had been

fully organized under Naval officers, a construction camp of some magnitude established on the radio station site and the actual construction of the station begun by May 28, 1918.

In the meanwhile the design of the towers, antenna system and radio equipment had been worked out, their manufacture was rapidly being completed in its entirety and parts of the equipment had begun arriving at Bordeaux.

Some difficulty had been encountered, particularly in connection with the shipments of such large quantities of fabricated steel for the 8 towers, owing to the prevailing shortage of shipping facilities and the danger to shipping from submarines, but practically all of the tower material and also the radio transmitters, had reached the station site in France by October 1st, 1918, an incredibly short period of time after the inception of the project even under normal conditions.

The construction of the station was proceeding at a rapid rate and every possible effort was being made to complete the station and get it in operation at the earliest possible moment when the urgent military necessity for the station was nullified and the original motive for its construction eliminated by the signing of the Armistice on November 11, 1918.

During the latter part of December, 1918, after it became apparent that hostilities would not be renewed, work on the station was stopped and the construction force disbanded and sent home, leaving only a skeleton force at the camp until the final disposition of the project could be determined. Subsequently the French Government expressed a desire to have the station completed by the United States as a post-war project, in view of the fact that the material and equipment had all been delivered to the station site, the towers and buildings were partly erected and sufficiently skilled labor was not available to France to insure the economical completion of the work. Our Government recognized the equity of the desire of the French Government in this respect and an agreement between the two governments was formally drawn up and signed which provided for the completion of the station by the

Navy, the French Government to assume the costs of all labor, material and equipment incident to the entire project.

A contract for finishing the erection of the towers was thereupon awarded by the Navy to an American firm, as it would have been unfair to expect the skilled American workmen who had been engaged on this work to continue with the work under their military status in view of the changed conditions.

The erection of the towers recommenced on May 4, 1919, and the tower work was completed in January, 1920. The work incident to the construction of the antenna and its suspension from the towers, the installation of the radio apparatus, etc., was continued with Naval personnel, including officers of the Naval Reserve Force and American civilian radio engineers employed by the Navy for duty at the station.

CROIX D'HINS AND THE LAFAYETTE RADIO STATION.

Sixteen miles southwest of Bordeaux, on the main line of the Midi railway, there is situated the small isolated village of Croix d'Hins, in the Department of Gironde.

The Lafayette Radio Station is situated about one-eighth of a mile from Croix d'Hins on a tract of land comprising nearly thirteen hundred acres.

The history of the name of Croix d'Hins is quite problematical, but the oldest inhabitant traces the origin around a Mr. Hintz, who, being the most important landowner, erected a cross near the roadside which came to be known as the Cross of Hintz, gradually assuming the present French name of "Croix d'Hins."

The village of Croix d'Hins, which consists of not more than six houses, the Midi Railway station and the Hotel Terminus, is located in the center of a vast tract of practically level country in one of the principal turpentine producing districts of the world.

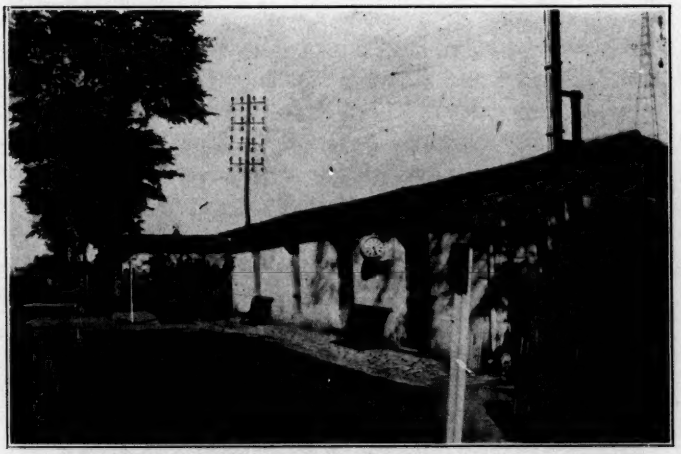


FIG. 5.—VIEW OF THE RAILROAD STATION AT THE VILLAGE OF CROIX D'HINS, FRANCE, SHOWING A PORTION OF ONE OF THE TOWERS AT THE LAFAYETTE RADIO STATION.

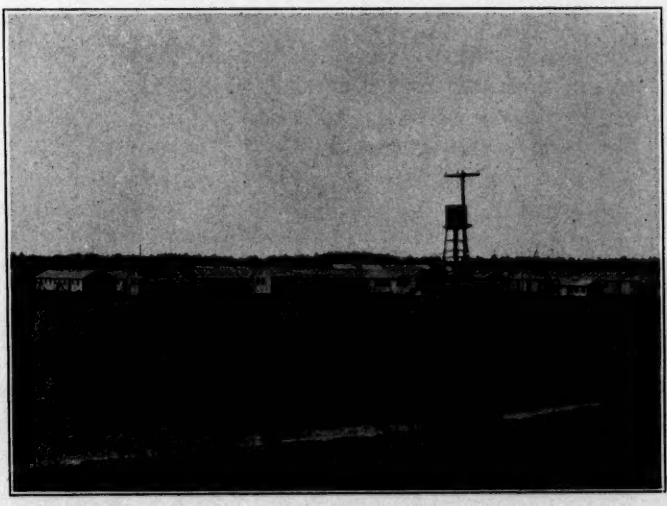


FIG. 6.—VIEW OF PART OF THE WORKING CAMP ESTABLISHED AT THE LAFAYETTE RADIO STATION WITH PORTABLE BUILDINGS AND MATERIAL SHIPPED FROM THE UNITED STATES.

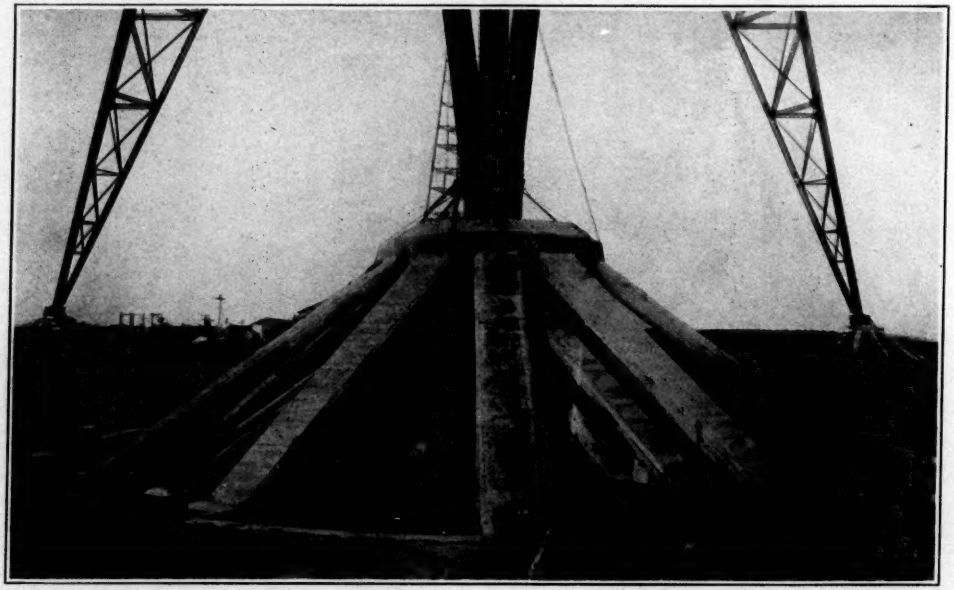


FIG. 7.—VIEW OF THE CONCRETE TOWER FOUNDATIONS AT THE LAFAYETTE RADIO STATION AS CONSTRUCTED BY THE FRENCH.

The Midi railway main line extends from Paris, through Croix d'Hins to Madrid, Spain. This line passes through Orleans, made famous by Joan of Arc; also through Tours, down the valley of the Loire in the wonderful chateau district of France, Poitiers, Angouleme, Bordeaux and Biarritz, whose names no doubt will bring back to the members of the American Expeditionary Forces many memories of France. Croix d'Hins is also connected with Bordeaux by one of the main highways which was called upon extensively in motor transportation of material for the erection of the radio station.

The Lafayette Radio Station is about 25 miles from the Atlantic ocean and about 375 miles from Paris. The extreme length of the radio station is constructed on the arc of a great circle passing through the Annapolis radio station and is about 400 miles north of, and at an approximate distance of 3,450 miles from the Annapolis station; about 7,000 miles from Buenos Aires, and more than 10,000 miles from Honolulu. There are no hills in the immediate vicinity of the radio station, the nearest mountains being the Pyrenees approximately 100 miles to the south.

The ground on which the Lafayette Radio Station has been established was formerly used as an aviation field; first by Bleriot, the manufacturer of aeroplanes, and later by the French military aviation service. When work was first undertaken to prepare this site by the United States Naval Detachment, many small aeroplane bombs were discovered scattered about the field, and it was no unusual occurrence to hear them exploding during the time the high brush was being burned off the field. In some instances the personnel engaged in this work barely escaped injury.

Surrounding the station on all sides are groves of heavy pine, while the fields in all directions are covered with thick growth; and in summer with the beautiful heather that is so abundant in Southern France. The ground is flat and low, and quite level; the soil is sandy, of a hard clayish formation, interspersed with iron-bearing strata. In dry weather the

ground is very hard and sandy, while during the torrential rains encountered at all seasons of the year, the entire field is almost a heavy mud flat. To provide against undesirable conditions during the rainy weather elevated board walks were constructed and surface drainage undertaken to an enormous extent; ditches and cross-ditches were necessary for proper drainage, which has also been a problem due to the exceedingly high water level, water being obtained under almost any conditions at a depth of not more than four feet.

The earth contains a high percentage of sulphur and iron which has been a source of trouble with the water used for drinking and culinary purposes. Iron in the soil appears as lateral streaks or veins and various conjectures as to the action of this mineral in the operation of the station have been advanced.

The nearest supply of good drinking water was at Bordeaux, and due to the utter isolation of Croix d'Hins, it became incumbent upon the Naval authorities to provide pure drinking water if the health of the men constructing the station was to be maintained at a high standard. To accomplish this purpose several wells were driven to a depth of thirty feet where an unlimited supply of water was encountered. Storage for this water was obtained by erecting a small water tower about thirty feet in height. The water found was good, though containing a considerable amount of hydrogen sulphite gas, a great deal of which was eliminated by permitting the water to stand in a second but smaller water tower, where it was aerated before drinking. When this water was first encountered, difficulty arose because of the mixture of surface water with it which made it appear as though the water was dangerous for drinking purposes. All this, however, was entirely eliminated by re-arranging the system of piping.

Before commencing the construction of the station, it was found necessary to build a road from the village across the railroad tracks and into the reservation for a distance of about a mile. Many difficulties were encountered due to the heavy

mud always present during the rainy season, finally necessitating the building of macadamized roads with solid foundation; this being required to support the heavy five-ton trucks and vehicles which were utilized in transporting a total of more than fifteen thousand tons of material. The material for this road was obtained from the nearest available source which was at the quarries in the town of Dax, about one hundred miles south of the station. Necessary railroad tracks were built around the towers with projecting spurs and finally connected up with the main line of the Midi Railway.

The climatic conditions at Croix d'Hins are of the most changeable nature. During the summer and fall of 1918, the weather was so extremely hot that work had to be discontinued during the middle of each day. In October, the rainy season begins. Heavy fogs were almost daily occurrences and by reason of this and the poor visibility, combined with slippery steel, a condition was created under which the tower work was carried on with great difficulty. Although it is ordinarily assumed that snow is a stranger in this section of France, some snow fell during the winter, but the ground was frozen only on rare occasions. The heat of the summer at times has been as much as one hundred and eight degrees with no air stirring, and it may well be compared with those extremely hot summer days in the narrow streets of New York between the tall buildings when the asphalt begins to bubble and one's shoes stick to the pavement. Whenever the wind commences to blow, it usually is from the direction of the sea and its velocity sometimes increases at the top of the towers to as much as sixty miles an hour.

All mechanical and electrical material for the station was made in and received from the United States; approximately 55 per cent from the port of New York and the remainder from the port of Philadelphia, on twenty-four different cargo and transport steamers operated by the United States Navy. All shipments passed through the War Zone without the loss of any material.

A total of eleven thousand six hundred and seventy-four tons was received from the United States. Structural material from French sources, amounting to three thousand five hundred and sixty tons was also purchased, bringing the total tonnage of material for the station up to fifteen thousand two hundred and thirty-four.

The steel used for the construction of the towers was obtained from the Pittsburgh-Des Moines Steel Company of Pittsburgh, Pennsylvania, and was fabricated before shipment. The radio electrical equipment was obtained from the Federal Telegraph Co. of Palo Alto, California.

Temporary buildings for the housing of personnel, administration, and storehouses, were made in the United States and shipped in sections. They are usually known as the "Dixey Type Barracks."

All buildings of a permanent nature were planned and erected by the French Government and include the Radio Power House at the western end of the antenna, midway between the towers, the Administration Building, various storehouses, living quarters for the French operating personnel, electrical transformer house, and a residence for the concierge near the entrance close to the Midi Railroad.

All permanent buildings are of concrete construction with red tile roofs, the natural color of the concrete being relieved on some buildings by blue trimmings and on others by red. To the southward, but near the buildings intended for the personnel, a large concrete tower fifty feet high has been erected for the permanent supply of drinking water and for fire protection. Water for cooling the arc radio transmitters is obtained directly by a pumping system installed in a pump house to the east of the main radio building and passes through a spray fountain near the pump house.

Due to the congested conditions of the railroads in France during the war, a considerable quantity of material from the French ports of Pauillac, Bordeaux, Bassens, St. Nazaire and Brest, was delivered to Croix d'Hins, by motor transport; how-

ever, railway cars, whenever available, were obtained; a total of fourteen hundred and five being required for this work.

In addition to the crushed stone obtained from Dax, for roads and tower base construction, it was necessary to obtain concrete from the camp of the American Expeditionary Forces at Souge, near Bordeaux, about 10 miles from the station. Practically all of this material was transported by American motor trucks, a very small portion being transported by railway.

The entire station, comprising nearly thirteen hundred acres, is inclosed by a barbed wire fence about four feet high, the entrance being through a decorative gate supported by columns of red brick faced with white stone trimmings.

The market facilities of Bordeaux, ordinarily not particularly extensive, were, during the war, strained to a breaking point and very little material of a suitable nature could be obtained from this source. Bordeaux has several foundries where castings required for replacement were obtained at times, provided, in the event of the castings being made of a composition metal, that the copper and brass required could be furnished by the Navy; fortunately the station was in a position to furnish this and construction continued without serious interruption. It was not anticipated that a condition would arise where the manufacture of castings would become necessary but in some instances material was lost in transit and replacements became a matter of serious consideraion where time was the factor.

Medical supplies, equipment for the laundry, for the bakery, the kitchen, machine shop, and the various auxiliaries required for a self-sustaining organization having the population of a small village, were all shipped from the United States and installed by Naval personnel; all Bureaus of the Navy Department being called upon for the material, food, and amusement facilities necessary to complete the camp and enable the Commanding Officer to push to a successful conclusion this unusual undertaking.

The United States Naval Camp, as finally constructed, consisted of six warehouses, a large mess-hall and galley, six barracks for enlisted personnel and one for officers; also three barracks with shower baths and wash rooms, a sick bay or hospital, laundry, recreation building, butcher house, tool house, carpenter and plumbing shop, canteen, Supply Office, Administration Building, round house for locomotives and cranes, cold storage, garage, garage repair shop, gas and oil storehouses, brig and artesian well pump house; and in addition two water tanks, and two septic tanks. The buildings were heated with ordinary American stoves and lighted by electricity.

All temporary buildings were assembled entirely by the Naval personnel. All buildings of the men's barracks were twenty feet wide, one hundred and five feet long, and one story high, arranged for forty men to occupy a building. Each man was supplied with a steel bed obtained from the United States and was required to look after his own bed; a form of Naval routine usually carried out on board ship was adapted to the new circumstances without difficulty. Of course this included inspections for cleanliness, and the airing of buildings to protect the health of the men.

An ingenious method of keeping a circulation of air through these buildings at night was the construction of ventilating ports underneath the stoves used for heating; and the windows arranged with side screens permitting certain ones to be opened without exposing the sleeping men to injurious drafts. Another contrivance used to insure the circulation of fresh air was ventilators located in the roof.

The courtesy of the officers' mess was extended to the French military and technical officers connected with the construction of the station; the dining room tables were arranged in groups in such a way that, where practicable, French and American officers occupied the same tables, the Commanding Officer and his two principal assistants having the French senior military officer as a guest at their table.

The Recreation Hall with a seating capacity of seven hundred, located at the southern side of the camp, afforded space for all the facilities necessary for the entertainment and amusement of the station personnel, was lighted by electricity, and heated by two large coal stoves and two exceedingly well built and well designed open fireplaces.

Through the courtesy of the Red Cross, Knights of Columbus and Young Men's Christian Association it was possible to fit the building up for theatricals and movies. Billiard tables were also provided as were also 2,000 books contributed by the American Library Association and the Red Cross.

Although this building was generally known as the Recreation Hall, on Sundays it was used for a chapel for divine services, arrangements for which were made by the Chaplain, who, on occasion, invited Chaplains from other organizations to conduct the service. In the absence of a Roman Catholic Chaplain, a church party attended services at the Catholic Church at Marcheprime, a small hamlet near the station.

To those not initiated, a Chaplain's duty in the Navy, ashore and afloat, is taken up with very many unusual activities, perhaps quite out of keeping with the layman's idea of religious activity. The Chaplain is the "Morale Officer" and under the Commanding Officer is charged with looking after the welfare and contentment of the men, their religious welfare, as well as their school instruction, all of which are very clearly defined in the Navy Regulations. On this station he was instrumental in arranging entertainments, evening smokers, selecting library books, distributing them and exchanging them with other stations. Educational classes under his charge were formed and academic studies taken up by those desiring them. A special class in algebra and French was organized for the men.

The absence of proper facilities for washing clothes and the difficulty experienced by the personnel using the available water to do their own washing with the conditions existing throughout France where open air washing and drying is resorted

to, made it incumbent upon the Naval Authorities to obtain laundry machinery from the United States. This machinery when received was installed in the laundry building which contained all the necessary facilities for washing, drying, and ironing clothing belonging to the personnel.

A small boiler for furnishing the hot water necessary and the steam for the drying room was installed in one end of the laundry, while in a small room nearby, two motor generators were installed to furnish current for electrical operation of certain machinery. The entire plant was fully capable of supplying the needs of seven hundred officers and men, without restriction, in addition to the hospital linen; all clothing which was "turned in" on Monday morning was delivered on Saturday morning. A small charge was made for the purchase of necessary material and for the payment of the laundry personnel, after which any profits were turned over to the Entertainment Fund for the benefit of the men. The laundry was in charge of a Chief Petty Officer assigned to that duty by the Commanding Officer, and his assistants were French civilians, the majority of whom were women.

The Hospital consisted of a building of standard type, 170 feet long, at the extreme easterly end of the camp. This building contained the Medical Officer's office, the Record Room, Linen Room, Sterilizing Room, Storeroom, Surgical Dressing Room, Dental Office, Drug Room, Laboratory Room, etc., in addition to the bathroom and the hospital kitchen. This was the only building in the camp heated with steam heat, which was supplied from a special plant attached to the hospital; this plant also supplied hot water for bathing facilities.

The main ward contained thirty-five standard U. S. Naval hospital beds and two isolation rooms containing one bed each. Later a small room was installed at one side and at the middle of the main ward for the purpose of an X-Ray room. During the epidemic of influenza in the winter of 1918 and 1919, a large tent was erected outside of the hospital for the excess patients which at one time numbered as many as twelve.

The station was very fortunate in that but three deaths occurred from this disease, one of whom was an officer; the bodies of these men were buried in American Expeditionary Force Cemetery No. 25, Talence, Gironde, France.

The personnel was kept singularly free from sickness other than that which occurred during the epidemic mentioned. Some difficulty was experienced with the water supply when the camp was first established, but after the increase in the depth of the artesian wells and the chlorination of the water during the summer months, this entirely disappeared and no further trouble was experienced. Pending the increase in well depth, all water was transported by trucks from Bouscat near Bordeaux.

The sewage of the entire camp, including the wash and bath rooms, galley, mess halls, barber shop, sick bay and officers' quarters, was carried through tile soil pipes above the ground to the main drainage ditch of the station. The sewage from certain buildings collected in a septic tank where it was retained for not less than seventy-two hours before it overflowed and joined the sewage from the galley and mess halls, with which it flowed through a large concrete soil pipe which carried it a distance of 50 yards into the adjoining woods and emptied into the main ditch draining the reservation.

CONCRETE FOUNDATIONS AND STEEL TOWERS.

A plan of the proposed concrete tower foundations, based on the American standard design, consisting of the ordinary mass concrete type foundation on piling had been forwarded to France from the United States, but the French adopted a different type and one that had not been previously encountered in radio tower work.

The French design of the foundations calls for a circular disc of strongly reinforced concrete, approximately 40 feet in diameter and sixteen inches thick, supported by 28 pre-cast square concrete piles, 35 feet long, surmounted by a central

pedestal 12 feet high by 8½ feet in diameter. The steel shoes for the tower columns rest on specially designed footings in recesses in the tops of these pedestals which are braced to the bottom disc by radial reinforced concrete buttresses. The tops of the foundations on which the towers rest are 12 feet above the surface of the ground. The artistic appearance of the completed foundations is said to form a rather striking contrast to the severe design of the towers resting upon them.

The steel towers are triangular in plan, 820 feet high, 220 feet center to center of columns at bases, 105 feet center to center of columns, 215 feet above bases, and 9 feet 8½ inches center to center of columns at the tops. A mast braced in each tower extends 18 feet above the tower tops, providing an actual height of 850 feet from the ground to the tops of masts. The highest self-supporting radio towers for antenna supports previously erected at any radio station in the world did not exceed 600 feet, towers of this height having been erected at the high power stations of the United States Naval trans-pacific high power circuit, at the Darien station in the Canal Zone, at the El Cayey station in Porto Rico and at the Annapolis station. The eight towers are arranged in two rows of four each, the rows being spaced 1,320 feet and the towers in each row likewise being spaced 1,320 feet apart. This provides for a total antenna area over the earth surface of 5,227,200 square feet, this antenna area far exceeding that of any other existing radio station.

The weight of each tower is estimated at 550 tons, and they are designed to withstand a horizontal pull of 11 tons at the tops, which represents the estimated maximum resultant pull due to tension in the antenna which they support together with the stresses caused by wind blowing on the antenna wires and supporting triatics and ice formations in winter. It is said that the great height of these towers cannot be realized by one observing them at the station, the impression being that they are not as high as the 600-foot towers at the Naval stations in the United States and its outlying possessions.

Unfortunately three men were killed during the construction of the towers, two Americans by falling from great heights from the towers and one Frenchman who was crushed by a locomotive used in connection with tower construction work. Work on the towers commenced about 7 o'clock in the morning and continued steadily until as late as 9:30 in the evening, except when extremely hot weather prevailed, during which times work had to be suspended during the middle of the day. The first tower was completed on September 15, 1919, the others following in rapid succession until the last tower was completed in January, 1920.

Paint to the extent of 5,000 gallons was necessary for the protection of the steel, two coats of what is known as Superior Graphite Paint being applied after the towers were erected.

THE ANTENNA SYSTEM.

The effective electro-magnetic energy contained in ether waves at points distant from a transmitting station is dependent on the height the antenna is suspended above the earth at the transmitting station, the conductivity of the earth under the antenna and in the immediate vicinity and the value of the electrical oscillatory current in amperes which the antenna wires are capable of carrying without "brushing" or corona formations, and the value of the current in amperes actually delivered to the antenna.

The desirability of providing very large antennas and supporting these large antennas at transmitting stations, for long distance work, the greatest practicable height above the earth's surface and the utilization of the most powerful radio transmitters to deliver the greatest possible current value to the antenna system, is therefore evident.

The antenna wires to which the electric current is delivered by the radio transmitter must be effectively insulated from the steel towers, by inserting material, which will not conduct electricity, between the antenna wires and the towers, thereby providing for the radiation of the electrical energy from the

antenna in the surrounding medium and preventing the flow of current directly to the earth through the steel towers. The best grades of porcelain or glass have been found to be the only available material for practical radio use which will withstand the high voltages to which high power station radio antennas are subjected.

The voltages to which the Lafayette antenna is subjected averages around 115,000 volts. The greater the value of current in ampères to be delivered to an antenna, the greater the size and number of copper wires which must be used to carry the current with the consequent increase in weight and wind pressure.

Practical considerations therefore with respect to the horizontal pull antenna supports of great height can be constructed to withstand, mechanical and electrical stresses which porcelain or glass insulators can be manufactured to withstand, and the extent of the initial cost and later maintenance of antenna supports and antenna systems, limit to a very large extent the effective transmitting ranges of high power radio stations.

It appears probable that this practical limit has about been reached at the Lafayette station.

Triatics, consisting of ¾-inch diameter galvanized crucible steel cable are suspended from the tops of the towers and stretch across the aisle between the four pairs of towers. The triatics are insulated from the towers by double porcelain rod insulators inserted between the towers and the ends of the triatics.

These four triatics support aloft 20 longitudinal copper cables consisting of 7 strands No. 12 wire, the cables being spaced along the supporting triatics about 60 feet apart, each cable being greater than one-half mile in length. The individual cables in the "flat top" of the antenna lead in fan shape formation downward, being brought close together about 200 feet below the flat top and from this point they are spaced about a foot apart with metal spreaders until they reach the

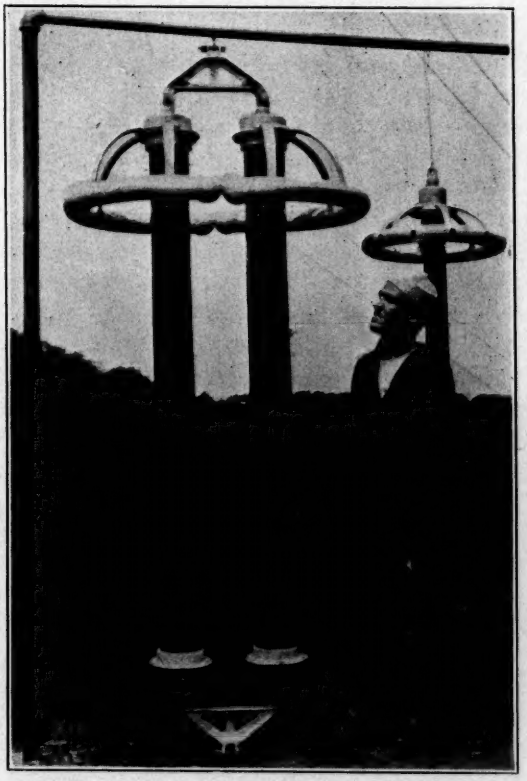


FIG. 8.—VIEW OF THE DOUBLE PORCELAIN ROD INSULATORS USED TO INSULATE THE STEEL TRIATICS FROM THE TOWERS AT THE LAFAYETTE RADIO STATION. THE SINGLE ROD INSULATOR SHOWN IN THE PICTURE ARE THOSE USED AT THE ANNAPOLIS STATION. NOTWITHSTANDING THE SIZE OF THESE INSULATORS, THOSE WHICH ARE ATTACHED TO THE TRIATICS AT THE LAFAYETTE RADIO STATION ARE HARDLY VISIBLE FROM THE GROUND DUE TO THE GREAT HEIGHT OF THE TOWERS.

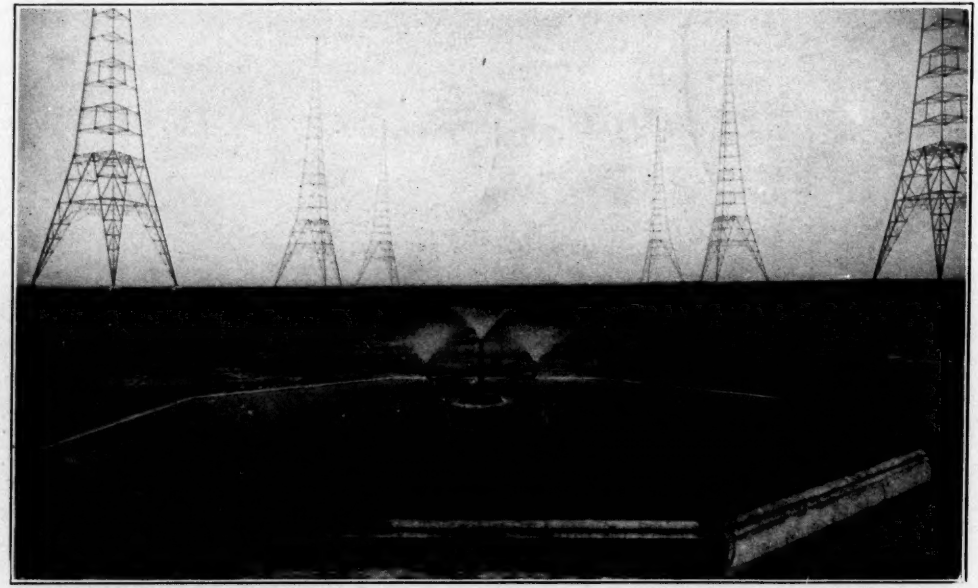


FIG. 9.—VIEW OF THE WATER COOLING POND AT THE LAFAYETTE RADIO STATION. HOT WATER BEING RETURNED TO THE POND THROUGH FIVE SPRAY NOZZLES AFTER BEING DISCHARGED FROM THE ARC EQUIPMENT.

radio building where they are bunched together and brought into the radio building through a heavy plate glass insulator and thence to the copper or positive electrode of the arc transmitter. The dead weight of the antenna system supported high above the earth from the 820-foot towers is about 3½ tons.

A special problem arose in connection with the insulation of the Lafayette antenna because of the extremely high mechanical loads which the triatics are required to carry, together with the high voltage current applied to the antenna, but by co-operation with leading engineers in the United States a special porcelain tubular insulator was eventually developed having a length of 10 feet with a mechanical ultimate strength of over 10 tons and an electrical flash-over voltage when dry of about 190,000 volts at a frequency of 50,000 cycles.

These insulators serve the double purpose of successfully withstanding the normal mechanical and electrical strains imposed, and acting as safety links to prevent overstressing the towers should excessive weight be added to the antenna by the formation of ice on the wires and supporting triatics, or excessive strain from high winds blowing on the wires, since the insulators will fail before the tower breaking point is reached causing the antenna to fall to the ground and thereby preventing overloading and possible collapse of the towers.

While the collapse of the antenna would be a serious temporary handicap, as it would render the station inoperative until it could be rebuilt and again hoisted into place, such an occurrence would, of course, be incomparably less serious than would the collapse of one or more of the 820-foot towers.

The maximum sag of the antenna wires with their supporting triatics is about 182 feet. The electrical effective antenna height as measured was found to be 564 feet. Since the towers including their foundations and masts provide an actual height of 850 feet above the ground and as the antenna sag does not exceed 182 feet, it would appear that the effective electrical height of the antenna would be not less than 668 feet which

corresponds to the actual height of the lowest part of the antenna above the surrounding ground surface. At all radio transmitting stations, however, the effective electrical height is reduced by the influence of the antenna supports on the intense electro-magnetic field surrounding the antenna. In the case of the Lafayette station, therefore, the electrical effective antenna height is unavoidably reduced by 104 feet due to the influence of the steel towers.

THE GROUND SYSTEM.

From the terminal of the carbon or negative electrode of the arc transmitter connections are made by copper strips to the ground system which consists of 94 copper plates each about one yard square, buried 5 feet below the power house floor. These are connected at their outer edges by 40 copper strips 3 inches by 1/16 inch to a bus ring of 6 No. 12 wires whose center is a point in the arc room midway between the two arcs and whose radius is 108 feet. This ground system is further supplemented by a row of 80 copper tubes or wells, 65 feet deep and 3-5/32 inches diameter, equally spaced on a circle whose center is the same as above and whose radius is 180 feet. These tubes are connected in pairs to the 40 strips mentioned above and further connected along the circumference by 6 No. 12 copper wires.

ELECTRIC POWER SUPPLY FOR THE LAFAYETTE RADIO STATION.

The electric power supply for the Lafayette Radio Station is obtained from a combined water and steam plant situated at Tuiliere in the upper regions of the Dordogne River, 60 miles from Bordeaux, and from a steam auxiliary plant, built during the war, at Floirac, about two miles beyond Bordeaux.

The Tuiliere plant has a capacity of about 25,000 kilowatts and operates by water when the river is high enough and by steam and water when the water supply is not sufficient. The high tension line is a three-phase 50,000-volt single-circuit line

of bare copper wire specially constructed for this station and extends from Tuiliere to Bordeaux, crossing the river twice above Bordeaux and once near the city opposite Floirac. The poles for this high power line are of light steel build with a lattice work mast effect. In case of complete failure of the Tuiliere plant, power may be obtained from Floirac.

The original power was transmitted to the station by a provisional line constructed by the station force at the very beginning of the work. The American authorities had been assured that power would be available, but such was not the case; and the principal electric company in the vicinity informed the Commanding Officer that it would not be possible for them to build a line as they had no labor available.

Immediate construction of a 13,000-volt line was then commenced by the Naval Authorities. This line entered at the eastern end of the station and was carried on wooden poles for a distance of eleven miles, where it was connected to the nearest high power line at the small town of Alouette. The wire and insulators were purchased by the Navy from the United States Army and the green wooden poles from local farmers. Actual construction of the line commenced July 4, 1918, and the entire work was completed in a little more than six weeks. It was not, however, until October of 1918 that this line was connected to the temporary power house containing two 250-kilowatt generators used in the erection of the radio towers. In the interval between the completion of this line and the month of October, the current was used for lighting the camp.

THE 1,000-KILOWATT RADIO TRANSMITTERS.

The transmitting equipment installed in the Lafayette station consists of two 1,000-kilowatt arc radio transmitters complete in duplicate throughout.

Duplicate transmitters were provided to guard against possible interruption to the service due to possible failure of one

transmitter remaining in condition to function continuously. With duplicate transmitting units installed repairs can be made to one while the other is in operation, thereby insuring continuous service in so far as the transmitters themselves are concerned.

The radio transmitters are of the Federal-Poulsen design of arc converter, originally produced in Denmark, but later developed and perfected in the United States, and are based on a method of obtaining radio frequency current oscillations by means of an electric arc burning in an airtight chamber with an atmosphere containing hydrogen.

Radio transmitters of similar design, but of lesser power, are installed in all of the medium and high-power shore radio stations of the Naval Communication Service and also on the capital ships of the Navy.

The essential items of the Federal-Poulsen arc converter comprise an airtight chamber of bronze, a "positive" electrode of copper, a "negative" electrode of carbon, two electro magnetic iron pole tips, a hydro-carbon feed supply and an electric current supply.

The construction of the arc converter is such that the positive and negative electrodes extend from the outside into the arc chamber, the positive electrode being insulated, by suitable surrounding material, from the bronze chamber and the end or tip being held in a fixed position within the chamber, the carbon electrode being held in place within the chamber by a bronze holder or sheath which makes direct contact with the bronze chamber. The carbon electrode can be adjusted with respect to its length outside the chamber to enable the striking or forming of the electric arc within the chamber, and for the proper adjustment of the length of the arc by slowly increasing the distance between the two electrode tips until the most advantageous length of the electric arc has been obtained for efficient operation. The carbon electrode is also provided with a rotating mechanism to enable the slow rota-

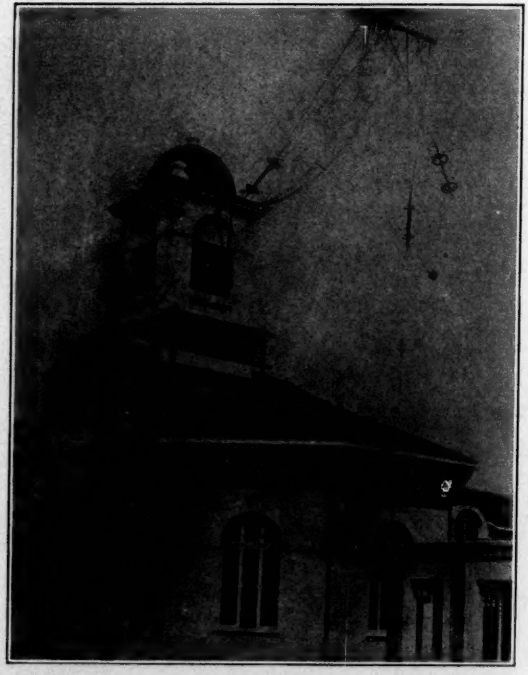


FIG. 10.—VIEW SHOWING "DOWN LEADS" FROM ANTENNA, AT THE LAFAYETTE STATION, ENTERING THE OPERATING BUILDING THROUGH PLATE GLASS INSULATOR.

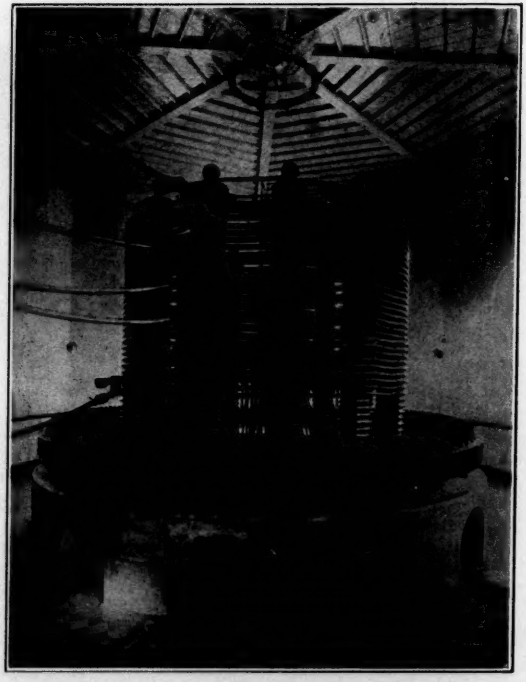


FIG. 11.—VIEW OF ANTENNA LOADING COIL AND SIGNALING SYSTEM.

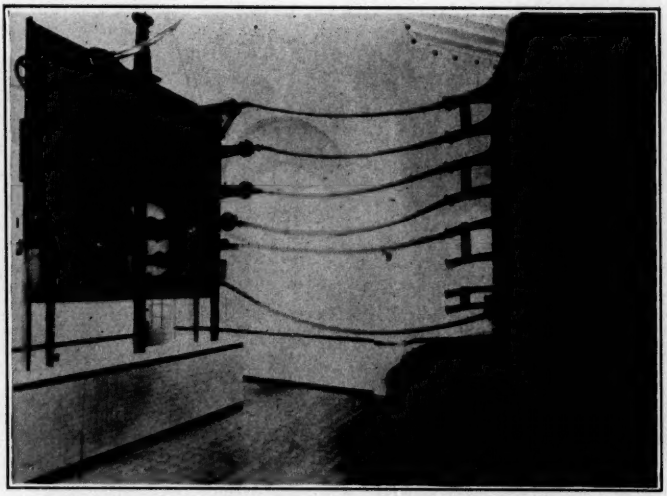


FIG. 12.—VIEW SHOWING WAVE CHANGER PANEL, PART OF ANTENNA LOADING COIL AND PART OF SIGNALING SYSTEM. THE NUMBER OF TURNS OF THE LOADING COIL USED IN THE ANTENNA CIRCUIT DETERMINES THE WAVE LENGTH EMITTED BY THE ANTENNA.

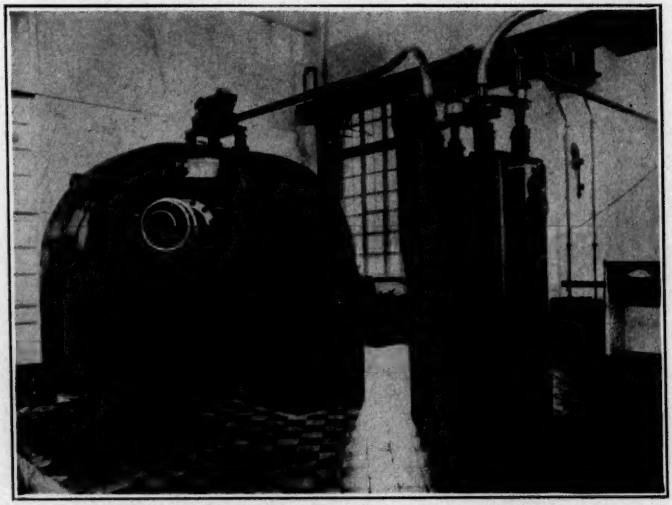


FIG. 13.—ONE OF THE 1,000 K. W. ARC TRANSMITTERS.

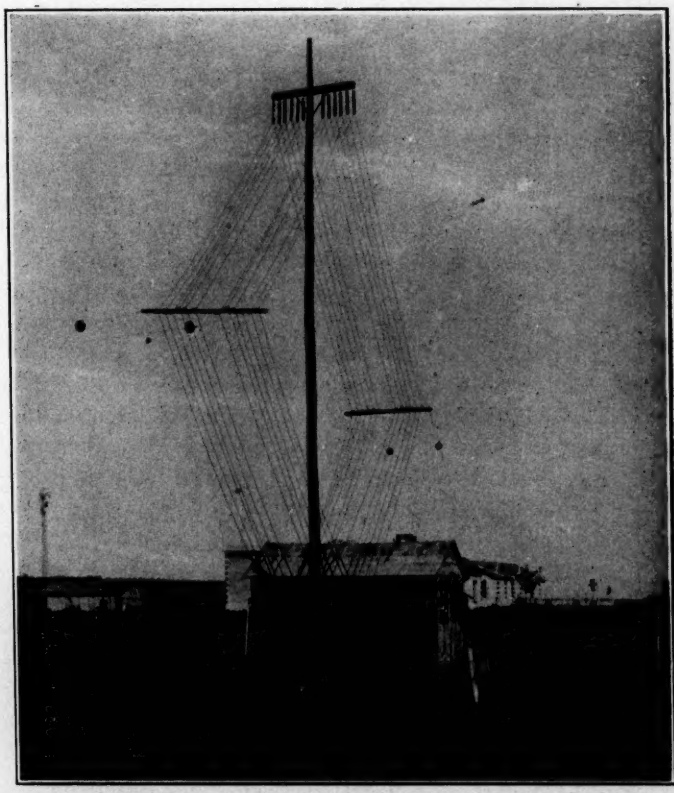


FIG. 14.—VIEW OF TEMPORARY RECEIVING ANTENNA AND RECEIVING STATION ERECTED AT THE LAFAYETTE RADIO STATION TO RECEIVE THE RESULTS OF TESTS FROM THE ANNAPOLIS STATION. NOTE THE STRIKING DIFFERENCE BETWEEN A RECEIVING STATION AND A TRANSMITTING STATION.

tion of the carbon tip while the arc is burning, by means of a small electric motor mounted outside of the arc chamber. The carbon electrode is rotated while the arc is burning in order to insure a smooth surface on the carbon tip and to prevent pitting or rapid burning away of parts of the tip, which would otherwise occur, thereby causing the arc to become unstable and resulting in poor operation, as the best separation of the electrodes to obtain maximum power from the arc is very critical. With the carbon electrode tip within the arc chamber constantly rotating while the arc is functioning, the burning away is slow and gradual all over the surface of the tip, and electrical instruments mounted nearby indicate when the tip has burned away sufficiently to warrant the operator making further adjustments which can readily be accomplished with the adjusting apparatus available and without stopping the functioning of the arc.

The two electro-magnet pole tips also extend from the outside into the arc chamber and are so placed within the chamber with respect to the positive and negative electrodes as to produce a strong transverse magnetic field or force between the arc electrodes within the chamber which tends to extinguish the arc. As an electric arc cannot be sustained within a strong magnetic field or force the result is that the arc flame expands upward from the electrode tips avoiding the strong magnetic force and causing a curvature in the arc flame and consequently an arc of greater length and power than would otherwise obtain between the electrodes.

The magnetic pole tips within the arc chamber are energized by winding insulated copper wire or strips around the iron, to which the tips are attached, outside of the arc chamber and causing electric current to flow through these windings.

Hydro-carbon gas is introduced into the arc chamber by the decomposition of alcohol or kerosene which is fed into the chamber, drop by drop, by suitable gravity feed mechanism and vaporized by the intense heat of the arc.

Electric current produced by the direct current radio generators flows through metallic connections from the generator windings to the copper or positive electrode terminal outside of the arc chamber, through the copper tip within the chamber, thence across the gap to the carbon tip, back through the negative electrode and metallic connections to the generator windings, thereby completing the generator power circuit and producing an electric arc within the arc chamber.

The wires of the antenna are also connected to the positive electrode terminal outside of the arc chamber and other wires which run to the earth are connected to the negative electrode terminal.

About 50 per cent of the electric power of the direct current flow from the direct current generators through the arc is converted into alternating high frequency radio oscillatory currents in the antenna circuit. This high frequency current oscillates back and forth between the antenna and the earth through the arc, the effects of which sets up powerful ether waves in the surrounding medium which travel away to all points of the compass.

Owing to the intense heat generated by the electric arc burning within the airtight chamber, it is necessary to carry off sufficient excess heat to prevent melting of the metals, therefore channels for forced water circulation are provided and circulating water is forced through the walls of the chamber, through the copper or positive electrode, through the bronze sheath of the carbon or negative electrode and through the iron magnetic pole tips. A large circulating water-cooling pond having a capacity of 40,000 gallons was constructed near the operating building from which cool water is forced through the equipment by electrically driven pumps, the hot water discharged from the equipment being conserved and returned to the pond through suitable spraying devices to assist in the cooling process.

The maximum contract requirements of the 1,000-kilowatt arc transmitters called for the deliverey of 550 ampères of current into a suitable antenna system, without corona or brush discharges occurring. Six hundred and ten ampères were obtained without difficulty during the official tests and without evidences of corona or brush discharges.

THE OFFICIAL TESTS OF THE LAFAYETTE STATION AND ITS INAUGURATION IN THE RADIO SERVICE OF THE WORLD.

Although one of the basic formulae in radio technique is to the effect that the greater the height antennas are suspended above the earth's surface at a transmitting station and the greater the current value in ampères delivered to the antenna circuit without causing corona or "brush" discharges, the greater will be the energy contained in the ether wave emitted by the transmitting station and therefore the greater the strength or "loudness" of the signals picked up at distant receiving stations, nevertheless the actual results to be obtained from a radio station cannot be accurately predetermined until the station has been established and tested in actual operation.

Radio transmitting (and also radio receiving) stations of exactly the same general characteristics and situated in the same general localities do not give the same results, but, on the contrary, often give widely varying results, certain transmitting and receiving stations situated in the same general localities being able to transmit and receive signals over much greater distances than others of the same class and at which identical equipment is installed.

From the experience gained as a result of the establishment and operation of a large number of radio stations, it is assumed that the natural electrical properties of the earth and the surrounding medium varies greatly in different localities which affects the functioning of the radio stations.

The results of the Lafayette station tests, therefore, were awaited with considerable anxiety, particularly in view of

the expenditure of funds involved in the establishment of the station and the circumstances under which its establishment was undertaken by the Navy.

No radio station of nearly such enormous power had previously been established or planned, the mechanical and radio electrical problems involved were of great magnitude and the correctness of the design of the equipment including the antenna system could not be finally established until the station had been placed in operation.

Moreover the project had long been a subject of discussion by the radio communication interests of the world and failure of the station to meet expectations would have resulted other than advantageously to the prestige of the United States and particularly to the Navy.

It is, of course, a matter of satisfaction to the civilian engineers who were identified with the work and to the personnel of the Naval Communication Service in general that the station not only proved successful for reliable transatlantic communication but that it was demonstrated, in so far as existing radio receiving stations were available for observation, that the station was able to transmit signals of sufficient intensity to be heard all over the world.

After the structural work had all been completed, the antenna hoisted in place, and the preliminary electrical adjustments and measurements made at the station, a 30-day schedule of tests was arranged in the Department, designating the daily time periods for transmission by the Lafayette station, also on which one of the 5 available wave lengths the signals for each test would be transmitted and the radio receiving stations to observe and report on the signals.

The receiving stations designated to observe the tests were located at widely different points in the chain of radio stations of the Naval Communication Service, the stations selected being Cavite, Philippine Islands; Agana, Guam; Tutuila, Samoa; Pearl Harbor, Hawaiian Islands; Cordova, Alaska; San Francisco, California; Darien, Canal Zone; Bar Harbor,

Maine, and the Naval Radio Laboratory, Bureau of Standards, Washington, D. C. The French radio service instructed their stations at Saigon, Indo China, and at other distant points to also observe the signals.

Ordinarily the "call" letters assigned to a radio station are used for testing the station, the call letters being repeated over and over again during the test intervals, as for example when the Annapolis tests were being conducted the call letters "NSS" as assigned to Annapolis were used.

In the case of the Lafayette station, however, the French call letters "LY" had been assigned as the international call letters of the station and it would not be feasible therefore to use radio call letters assigned to the United States, therefore the name assigned to the station was used as the test signals instead of either the French official call letters or a combination of letters assigned for international use by American stations.

Lafayette's signals were readily copied at Bar Harbor and the Naval Radio Laboratory, Bureau of Standards, observing stations during all of the tests, the strength of the signals being reported as being from five to eight times greater than signals from the next most powerful distant station, namely, the German station at Nauen, which station had been greatly enlarged and improved after our entrance into the war.

Lafayette's signals were also copied without difficulty at Cavite, San Francisco and Darien during most of the tests, and were audible although not always readable at Agana, Pearl Harbor, Tutuila and Cordova, due to the fact that suitable receiving equipment to receive the long wave signals from Lafayette was not available at these distant stations.

Reports by the observing stations were forwarded to the Department by radio following each test, these reports being condensed and forwarded by radio to the Lafayette station through the medium of the Annapolis station. As a consequence the engineers at the Lafayette station were apprised of

the results obtained at distant stations a few minutes after each test had been completed and this information enabled them to judge of the effectiveness or otherwise of any modifications or changes made in the equipment or the antenna circuit for each individual test.

A total of 126 tests were run during the 30-day period, these test intervals ranging from fifteen minutes to five hours' continuous transmitting, thereby affording opportunities to thoroughly test the equipment as well as to carefully observe the strength of signals at distant stations.

The results of the tests not only demonstrated the fact that reliable communication can be had between France and the United States by radio during all seasons of the year and at all hours of the day and night in any volume of traffic within the capacity of the station but also demonstrated the fact that Lafayette's signals can be heard at suitably equipped radio receiving stations all over the world.

The tests being completed on September 20, 1920, and the station pronounced satisfactory, final adjustments were made to the equipment for regular service, the French operating contingent, which had been assigned to the station at the beginning of the tests, were given final instructions in the care and operation of the apparatus and the station was informally turned over to the French for operation as of November 15, 1920.

On December 18, the station was formally turned over to France with appropriate ceremonies, the French Government being represented by M. Deschamps, Assistant Secretary of Posts and Telegraphs, who unveiled the commemorative bronze plaque which had been put in position over the main entrance to the radio operating building.

The design of the commemorative plaque embodies two panels surmounted by a combination of the coat of arms of France and the United States. The following inscription is engraved on the panels in both English and French:

LAFAYETTE RADIO STATION.

In Honor of General Lafayette.

Conceived for the purpose of insuring adequate and uninterrupted transatlantic communication facilities between the American Expeditionary Forces engaged in the World War and the Government of the United States of America.

Erected by the United States Navy in conjunction with and for the Government of France.

Work Started 28 May, 1918.
Completed 21 August, 1920.

The following congratulatory radiogram from the Secretary of the Navy was sent through the Annapolis radio station to the Lafayette station on December 18th:

"Washington, D. C., Dec. 18, 1920.

Minister of Marine, Minister of War and
Minister of Posts and Telegraphs,
Care United States Naval Attaché,
Lafayette Radio Station.

Cordial felicitations are extended to the Republic of France through the medium of the Annapolis Radio Station on the occasion of the inauguration of the Lafayette Super High Power Radio Station. It is our firm conviction that as a result of the mutual co-operation and endeavors of the representatives of the French and American peoples engaged in the work incidental to the establishment of the great Lafayette Radio Station a notable advance has been made in the scientific progress of the world which will result in enduring benefit to France and to all mankind.

Josephus Daniels,
Secretary of the Navy."

Shortly afterwards the following radiogram from the Lafayette station was received by the radio receiving station in the Navy Department:

"LAFAYETTE RADIO STATION, FRANCE,
December 18, 1920.

To the Secretary of the American Navy.
Washington, D. C.

I desire that the first message sent after the official inauguration of the Lafayette Radio Station be a cordial greeting to the Republic of the United States of America. In the name of the French Government I send many thanks to the American Navy for the great part which it played in the construction of the most powerful radio station in the world. This collaboration maintained during the period of peace strengthens still further the unalterable friendship born of common struggles and victories.

DESCHAMPS,
Asst. Secretary of Posts and Telegraphs."

Upon the formal transfer of the station to France the last of the American contingent was withdrawn and the station was inaugurated by the French in the international radio service of the world and it is now in daily operation transmitting communications and press matter to the United States and other distant countries.

The total cost of the station approximated four million dollars.

Aside from its practical utility, the Lafayette Radio Station stands as a monument in France to the United States Navy and it is a fitting memorial to the Naval Communication Service in its efforts to safeguard the welfare of our forces engaged in the World War.

NOTES ON THE WIRING CIRCUITS FOR MAIN PROPULSION, U.S.S. *NEW MEXICO*.

By F. W. Hehre, E. E.,
Assistant Professor of Electrical Engineering, Columbia University.

Before taking up the actual consideration of the propulsion wiring and circuits of the U.S.S. *New Mexico*, it is advisable first to consider the entire installation and its control, in a general way.

To drive the *New Mexico* at 21 knots requires 167 r.p.m. and 28,500 horsepower, and cruising at 15 knots requires 116 r.p.m. and 9,500 horsepower. It will be seen that these two important speeds are nearly in a ratio of 3 to 2 and that the power required at 15 knots is less than half that needed at 21 knots.

To supply the alternating current power for the motors, one or more alternating current generators had to be provided and evidently together they would have to be capable of supplying, at least, somewhat over 28,500 horsepower to allow for the efficiency of the motors. Since at cruising speeds only 9,500 horsepower are necessary, the reasons for installing two generators, each capable of developing 11,500 kilowatts, or about 15,000 horsepower, are evident. At cruising speeds only one generator need thus be operated, leaving the other for a standby. Incidentally it should also be noted that a fully loaded generator is more efficient than two lightly loaded ones. Also three or more smaller generators would have complicated the control to an unnecessary degree.

Note—There are no diagrams 9, 10, 29 and 30.

We have, then, that for ordinary cruising speed, one generator supplies four motors, while above that speed, two are needed. The generators, when both are operated, are, however, not run in parallel, but each supplies the two motors on the same side of the ship independently of the others; that is, the starboard generator runs the two starboard motors and the port generator the two port motors, there being no electrical connection between the two circuits. In diagram A, a simple single line sketch of the entire plant is shown. When only one generator is operating, the Bus Tie switch is closed and the Disconnecting switch of the other generator is open. If both generators are supplying power, the Bus Tie switch is open.

It is a characteristic of induction motors, that they operate within one or two per cent of some fixed multiple or submultiple of the speed of the alternating-current generator driving them. If a 2-pole alternator, running at 1,800 r.p.m., drives a 24-pole induction motor, the latter, when loaded, will run one or two per cent slower than one-twelfth the alternator speed, or about 148 r.p.m. A 36-pole induction motor, running from the same alternator, would make a little less than one-eighteenth of 1,800 r.p.m., or about 99 turns. If driven from an 8-pole alternator making 900 r.p.m., a 4-pole induction motor would run at about 1,780 r.p.m., or nearly twice the speed, etc. It is the ratio of alternator to motor poles that decides the motor speed. Further, if the alternator speed is varied, the speed of the motors will change in the same ratio. The *New Mexico's* alternators are bi-polar.

In order, then, to change the speed of the motors, it is necessary to adjust the speed of the generators. Up to 15 knots the motor windings are arranged so as to develop 36 poles and to obtain motor speeds from 38 to 116 r.p.m., the generator speeds are varied from about 700 to 2,100 r.p.m. For speeds above 15 knots the motor windings are rearranged, by means of the "Pole Changing" switches, to give 24 poles, and to obtain motor speeds from 116 to 170 r.p.m., it is necessary to run the generators from about 1,400 to about 2,100

r.p.m. The adjustment of the generator speed is performed by the operator at the switchboard in the center engine room, through a mechanism acting on the governor of the generator turbine.

An alternating-current generator must be supplied with direct current for its fields, in order that it may generate voltage and thus deliver current and power. The voltage generated by the generator is nearly proportional to the value of its field current. If its field current is zero, the generator is dead.

As is usually done on shore, direct current for the generator fields is furnished by turbine-driven, direct-current generators, called "exciters," one for each main generator, each capable of delivering 800 kilowatts at 240 volts, three wire.

As the speed of the generator and hence of the motors is varied, it becomes necessary to vary the voltage impressed on the motors, in order that they operate economically and at a good power factor, yet do not fall "out of step." Also when starting up or reversing the motors, it is necessary to momentarily impress on them a voltage considerably above the value required for continuous operation. To accomplish these variations of voltages requires variations of field current, and some method of control is evidently required. This is ordinarily done on shore, by connecting the armature of the exciter directly to the field of the generator and then varying the generator field current by varying the voltage of the exciter, the voltage of the exciter being controlled by increasing or decreasing the resistance of its field circuit. For reasons that will appear later, this method was not used on the *New Mexico*, although it may be employed on later ships, which are to be electrically propelled.

The entire control of the propulsion thus centers about the field circuits of the generators, for if the generators have no field current they can generate no voltage and so deliver no power to the motors. Thus all switching, such as reversing, changing ratio of generator to motor speeds by changing the

number of poles on the motors, cutting motors or generators in or out, is done *with the fields of the generators open*. This is necessary to avoid shock to the system, burning out of switches, etc. This is so important that interlocks, both mechanical and electrical, are provided so that such switching can be done *only* with the generator fields open.

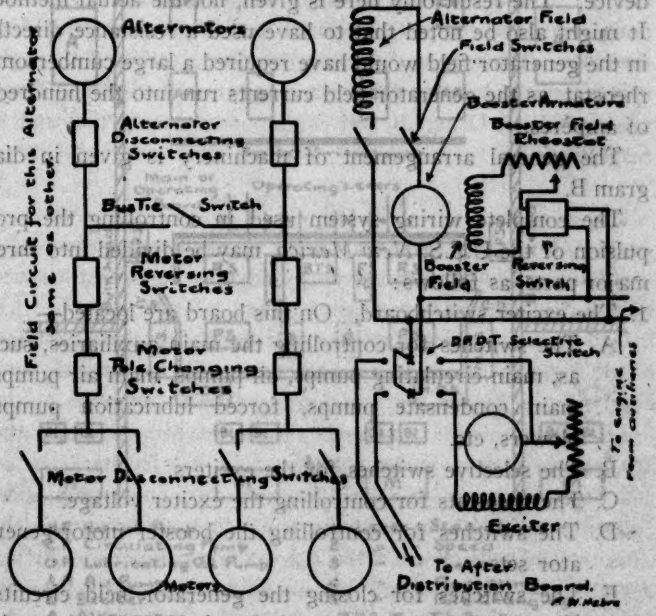
The arrangement of engine room spaces of the *New Mexico* is similar to that of turbine-propelled vessels of her class, although this is necessary only for motors and shafting. Advantage is taken of this feature of "Electric Drive" in later ships, resulting in an arrangement giving greatly superior underwater protection. The two usual dynamo rooms for supplying ship's light and power are located forward and aft, as in other vessels of the same class. The exciter voltage was made the same as the ship's power voltage, which thus made the latter a standby source of power for running the engine room auxiliaries. In later ships the dynamo room will be a part of the main engine rooms and all the direct-current generators installed will be capable of being used either as exciters or for supplying ship's power.

All of the main turbine auxiliaries on the *New Mexico*, that is, the main air, main condensate, main circulating and forced lubrication pumps, are motor driven and require constant voltage for their operation. These may be operated from the after distribution board but generally are driven from the same exciter that supplies the generator field current. The exciter thus must not only furnish constant voltage to the motors of the auxiliaries, but also must supply field current over a wide voltage range for the generators. This, as said before, is necessary because for each speed of the main motors there is a "best" voltage and also because bringing the motors into step when starting or reversing, necessitates a considerable increase in voltage and therefore in generator excitation. To meet these requirements, boosters, capable of either bucking or boosting the constant exciter voltage, are placed in series in the generator field circuits.

Reference to diagram A will show in a simple way, how this is done. The double pole, double throw switch shown, allows power to be taken either from the exciter, which is the normal source, or from the after distribution board which would only be used in case of emergency. Three circuits are fed from the blades of this switch. The field, with the armature of the booster in series and provided with two electrically operated switches, is the most important. Then comes the field circuit of the booster, with a resistance for controlling the amount of current in the booster field and a reversing switch for controlling its direction. The third circuit, that to the engine room auxiliaries, is simply indicated. With

Diagram A.

One line sketch of A.C. Circuits and Alternator Field Control.

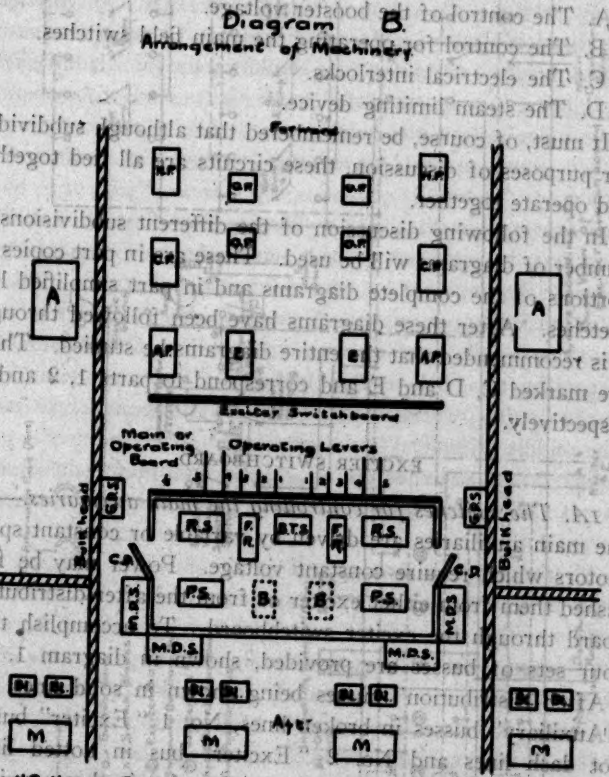


current through the booster field in one direction, the polarity of the booster will be such as to add its voltage to the exciter and give a larger current to the generator field. If the booster field current is reversed, the polarity of its armature will reverse and it will oppose or buck the exciter voltage and a smaller generator field current will result. The value of the booster voltage in either direction is controlled by the booster field rheostat. Actually, as will be seen later, the field rheostat and reversing switch are combined in a more complicated device. The result only here is given, not the actual method. It might also be noted that to have used a resistance directly in the generator field would have required a large cumbersome rheostat, as the generator field currents run into the hundreds of ampères.

The general arrangement of machinery is given in diagram B.

The complete wiring system used in controlling the propulsion of the U.S.S. *New Mexico*, may be divided into three major parts, as follows:

1. The exciter switchboard. On this board are located—
   - A. The switches for controlling the main auxiliaries, such as, main circulating pumps, oil pumps, main air pumps, main condensate pumps, forced lubrication pumps, blowers, etc.
   - B. The selective switches for the exciters.
   - C. The rheostats for controlling the exciter voltage.
   - D. The switches for controlling the booster motor-generator sets.
   - E. The switches for closing the generator field circuits. These switches are operated electrically from the main switchboard.
   - F. The selective switches for energizing the operating busses, located on the main switchboard.
2. The alternating current wiring. This comprises—
   - A. The power wiring and switches between generators and motors.
   - B. Wiring for meters, balance relays, etc.



H.P. Hotwell Pump
C.P. Circulating Pump
O.P. Lubricating Oil Pump
A.P. Air Pump
E Exciter
A Alternator
G.D.S. Generator Disconnecting Sw.
M.D.S. Motor Disconnecting Switch
R.S. Motor Reversing Switch
P.S. Pole Changing Switch
F.R. Booster Field Rheostat

1 Lever - Steam Limit
2 " - Speed
3 " - Field
4 " - Reversing
5 " - Pole Changing
B.T.S. Bus Tie Switch
C.D. Coil Door
Bl. Motor Vent. Blower
M Main Motor
B Booster. Installed on Platform are Operating Coil Cabinets

3. The "Control" wiring, which includes—
   A. The control of the booster voltage.
   B. The control for operating the main field switches.
   C. The electrical interlocks.
   D. The steam limiting device.

It must, of course, be remembered that although subdivided for purposes of discussion, these circuits are all tied together and operate together.

In the following discussion of the different subdivisions, a number of diagrams will be used. These are in part copies of portions of the complete diagrams and in part simplified line sketches. After these diagrams have been followed through, it is recommended that the entire diagrams be studied. These are marked C, D and E and correspond to parts 1, 2 and 3, respectively.

EXCITER SWITCHBOARD.

1A. The switches for controlling the main auxiliaries.—All the main auxiliaries are driven by variable or constant speed motors which require constant voltage. Power may be furnished them from either exciter or from the after distribution board through the exciter switchboard. To accomplish this, four sets of busses are provided, shown in diagram 1, the "After Distribution" busses being shown in solid lines, the "Auxiliary" busses in broken lines, No. 1 "Exciter" bus in dot dash lines and No. 2 "Exciter" bus in dotted lines. Selection is made by means of a triple-pole, six-throw switch. This switch consists of three sets of triple blades, each set operating together (see 2), shown as 2, 4 and 6 in diagram 1, and four sets of triple clips, 1, 3, 5 and 7. Any set of blades may be thrown either way, i.e., blades 2 may be thrown into either clips 1 or 3, etc.

To blades 4 are connected three feeders from the after distribution board, giving 240 volts, three wire. Connected to the same clips are the "After Distribution" busses (solid

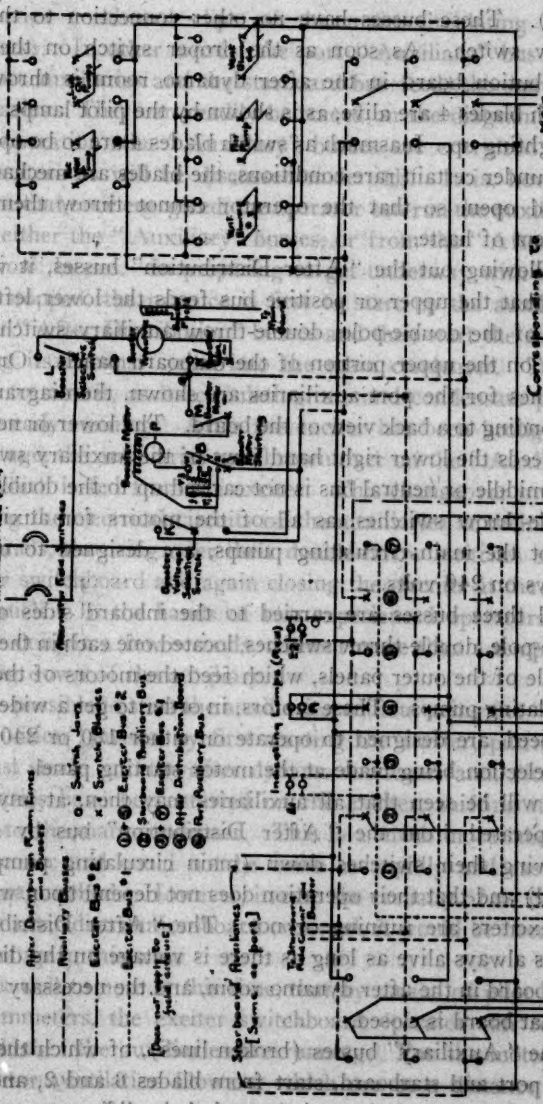


Diagram
Corresponding to Back View of Master Switchboard
Main Switchboard
Starboard Auxiliary Bus
Port Auxiliary Bus
Starboard Auxiliary Bus
Port Auxiliary Bus
Switchboard Auxiliaries
Main Circulating Pump

lines). These busses have no other connection to the six-throw switch. As soon as the proper switch on the after distribution board in the after dynamo room is thrown in, switch blades 4 are alive, as is shown by the pilot lamps (red), A, lighting up. Inasmuch as switch blades 4 are to be operated only under certain rare conditions, the blades are mechanically locked open, so that the operator cannot throw them in a moment of haste.

Following out the "After Distribution" busses, it will be seen that the upper or positive bus feeds the lower left hand jaws of the double-pole, double-throw auxiliary switches, located on the upper portion of the outboard panels. Only the switches for the port auxiliaries are shown, the diagram corresponding to a back view of the board. The lower or negative bus feeds the lower right hand jaws of the auxiliary switches. The middle or neutral bus is not carried up to the double-pole, double-throw switches, as all of the motors for auxiliaries, except the main circulating pumps, are designed to operate always on 240 volts.

All three busses are carried to the inboard sides of two triple-pole, double-throw switches, located one each in the lower middle of the outer panels, which feed the motors of the main circulating pumps. These motors, in order to get a wide range of speed, are designed to operate on either 120 or 240 volts, the selection being made at the motor starting panel.

It will be seen that all auxiliaries may then, at any time, be operated from the "After Distribution" bus by simply throwing their switches down (main circulating pumps, inboard) and that their operation does not depend upon whether the exciters are running or not. The "After Distribution" bus is always alive as long as there is voltage on the distribution board in the after dynamo room, and the necessary switch on that board is closed.

The "Auxiliary" busses (broken lines), of which there are two, port and starboard, start from blades 6 and 2, and feed the upper clips of the switches of their different respective

auxiliaries (outboard clips of the main circulating pump switches). In other words, the port "Auxiliary" bus feeds the port auxiliaries and the starboard bus feeds the starboard auxiliaries. They can readily be traced on the diagram.

In operation, the "Auxiliary" busses are energized from the exciters as will be discussed under 1B. It is, however, evident that once energized, the operator can run the auxiliaries from either the "Auxiliary" busses, or from the "After Distribution" busses. In preparing to get underway with everything stopped, the practice is first to start up the auxiliaries on the "After Distribution" busses and then start the exciter, putting its exhaust steam into the main condenser. This is ready to take it, as its circulating, air and condensate pumps are already running. After the exciter has been brought up to voltage, the auxiliaries are thrown over on the "Auxiliary" bus, which is fed from the exciter. This changeover involves opening the electrical circuits of the auxiliaries at their starting panels, throwing over their double-throw switches on the exciter switchboard and again closing the circuits at the starting panels. In the hands of two experienced operators, this can be done in a few seconds, without more than a temporary slowing down of the auxiliary.

It is possible to start the auxiliaries without using the "after Distribution" busses, by first starting the exciter, putting its exhaust steam into the after dynamo condenser and, after the auxiliaries have been started on the exciter, shifting its exhaust to the main condenser. This is a much more laborious changeover and could not be made as rapidly and easily as the usual method. However, in case the casualty of no voltage on the after distribution board occurred, it would be necessary to start up in this way.

It is well to note at this time, that by means of pilot lamps and ammeters, the exciter switchboard operator can readily tell whether the auxiliaries are running. For the motor and generator ventilation blowers, which are at a distance from

the board or in other compartments, pilot lamps are placed on the exciter switchboard itself. For all the auxiliaries, except the oil pumps, in the same compartment with the exciter switchboard, ammeters on the exciter board are provided and, in addition, in the case of the main circulating pumps, a pilot lamp on the starting panel, in easy view from the exciter board. By means of the ammeters, the operator can see at a glance how much load the auxiliaries are carrying. A special watch is kept on the oil pumps to insure their operation.

1B. *The Selective Switches for the Exciters.*—The exciters are directly connected to their respective "Exciter" busses. No. 1 "Exciter" bus (dotted) then taps on to clips 3 and 7 and No. 2 "Exciter" bus (dot dash), to clips 1 and 5. (Pilot lamps E1 and E2 (red) indicate whether these busses are alive or not.) Now, by throwing blades 6 into clips 7, the port "Auxiliary" bus is energized from exciter No. 1. If blades 6 are thrown inboard into clips 5 the port "Auxiliary" bus is energized from exciter No. 2. Similarly the starboard "Auxiliary" bus can be energized from either exciter by throwing blades 2 one way or the other.

Thus the auxiliaries on either side may be operated from either exciter and as (as will be seen later) the generator field circuits and the "Operating" bus are taken from the "Auxiliary" busses, the same is true of them. That is, either generator field, may be fed from either exciter.

A possible casualty that can be considered at this time is that of the after distribution board going dead, due to both after dynamos going out of commission and no power available from the forward distribution board. If one exciter can be spared in the center engine room, it can be utilized to supply power to the after distribution board and through this to the ship's circuits, by throwing blades 4, either right or left, into clips 3 or 5, depending on which exciter is available. It must, however, be carefully borne in mind, that in no case should blades 4 be thrown while alive, as it would entail putting an

exciter in parallel with the after distribution board. This would be dangerous, particularly if the exciter were not running.

1C. The Rheostats for Controlling the Exciter Voltage. Diagram 2.—The exciters are 3-wire, compound-wound machines with commutating fields, both series and commutating field windings being in two sections. Current flowing from the positive brushes passes through one-half the series and commutating windings, which are placed on alternate main and commutating poles, respectively, and then out on the positive leg of the three-wire system. Current returning from the negative side of the three-wire system flows through the other half of the series and commutating windings to the negative brushes. This arrangement is necessary to provide proper compounding and commutation for all degrees of unbalanced current on the two sides of the system.

The exciters being self-excited, diagram 2, the shunt field current is taken off at the positive brushes, passes through the rheostat on the back of the exciter board and back to the negative brushes. By varying the amount of resistance in the field rheostat by means of the hand wheel on the front of the board, the voltage of the exciter is controlled, being read on the voltmeters on the board. Under normal operation this is maintained at 240 volts.

1D. The Switches for Controlling the Booster Motor-Generator Sets.—As has been said before, the main generators, in order to meet different conditions of load and sea, require values of field current which vary between wide limits. Starting the motors, with the ship dead in the water, requires not more than 300 ampères through the generator fields to produce sufficient voltage for the motors to pull into step. As the resistance of the generator fields is about 0.47 ohm, cold, this requires about 141 volts. With the motors running at cruising speeds in a smooth sea, less than 250 ampères, or 117.5 volts, are sufficient. To effect quick reversal of the motors,

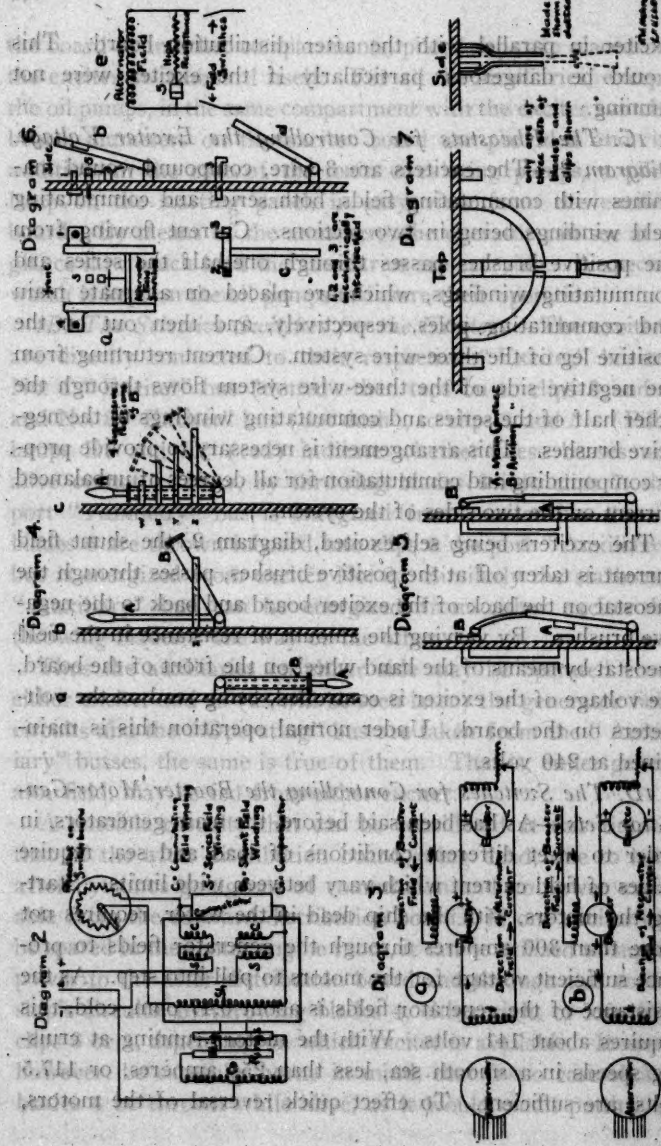


Diagram 1
Diagram 2
Diagram 3
Diagram 4
Diagram 5
Diagram 6
Diagram 7
Top
Side

with the ship going ahead at maximum speed, requires about 500 ampères generator field current, or 300 volts on the field, whose hot resistance might then be 0.6 ohm.

In order to obtain such variations of field current from exciters furnishing constant voltage (at either 120 or 240 volts), boosters, capable of either boosting or bucking this constant voltage, are used. These sets consist of a booster generator driven by a direct connected, constant speed, shunt motor. The booster generator or as it is generally called, the booster, has its armature connected in series with the generator field circuit, and its field separately excited from the main switchboard. If current (see diagram 3*a*) in one direction be sent through the field of the exciter, it causes the booster to be of different polarity from the exciter and the voltage impressed on the generator field will be the difference between the exciter and booster voltages. When, however (diagram 3*b*), the current through the booster field is reversed, the polarity of the booster also is reversed and it adds its voltage to that of the exciter. The control of the booster field current and its reversal is effected by means of a rheostat, controlled from, and mounted back of, the main switchboard.

To control the entire booster set, five switches in all are used, two single-pole, double-throw, two single-pole single-throw and one single-pole, "pump" starting switch. All of these have their handles painted red, showing that they must *not* be operated when the generator field is closed, or even in any case heedlessly thrown.

To control the booster motor, a tap is taken from the upper "Auxiliary" bus to the blade of the "pump" starting switch. (See diagram 1. The booster circuits here represented are simplified line sketches.) The "pump" switch serves to start the booster motor and is of special construction. It consists of an insulated arm A, and a copper blade B, both of which hang down (as in diagram 4*a*) when not in use. To start the booster motor, the operator grasps arm A and moves it up against the board as in 4*b*. By means of a pawl, arm A drags

arm B after it and when A is up as far as it will go, arm B will be as shown in 4*b*, making contact with a copper contact Z. Arm A is then brought back again to B and again moved up to the board, bringing arm B in contact with Y (diagram 4*c*) and so on, until finally B is up against the board, in contact with W.

Reference to diagram 1 will show what happens as this switch is operated. When blade B makes contact with Z, current passes directly from the upper "Auxiliary" bus to the motor field and also through resistance *r*1, fuse *f* and resistances *r*2 and *r*3, to the armature. Field and armature currents unite at P, pass through the single pole switch M to Q, and return to the lower "Auxiliary" bus. Successive positions of blade B (diagram 4*c*) gradually eliminate the starting resistances, the "pump" feature of the switch compelling the operator to start the motor properly. Contact Z is made for all positions of arm B in order not to put resistances *r*1, *r*2 and *r*3 in series with the field as arm B moves up. Contacts Y and X are opened as soon as arm B has moved past them. Blade B is also interlocked with the generator field switches as will be described in 1E. Fuse *f* is inserted to guard against any abnormal condition in starting, but is in circuit only during the first step (B in contact with Z). Switch M is inserted so that potential can be removed from both sides of the booster motor when not running to permit cleaning, repairs, etc.

For the generator field circuit, taps from the upper (or positive) and the neutral "Auxiliary" busses are brought to the clips of the single-pole double-throw switch K. From its blade the current passes directly to one pole of the generator field switch (to be described in detail in 1E) thence through the generator field and back to the other pole of the field switch. Switch K, if thrown up, takes 240 volts from the exciter, while if thrown down, takes 120 volts. From the second pole of the field switch the current goes to the blade of switch L. If this is thrown up, the current continues through the armature of the booster, through N, to Q and thence to the negative

"Auxiliary" bus. This is the normal operating circuit. Should anything happen to the booster so that it cannot be operated, switch L is thrown down, so that the current goes directly to Q, taking the booster out of circuit. This change must be made with the generator field open. Switch N is provided so that negative potential can be removed from the booster for repairs, etc.

If the booster is cut out, the voltage applied to the generator field and thus the generator field current must be controlled by means of the exciter field rheostat. It is also necessary to shift the auxiliaries to the after distribution board, as the exciter voltage now will be variable and hence not correct for their proper operation.

It will be seen that although exciters are interchangeable, the boosters are not. The port booster can be operated only with the port generator and the starboard booster only with the starboard generator. This is done in order to eliminate an additional switch which would be necessary to make the boosters interchangeable and, while giving simplicity, sacrifices the emergency feature embodied in being able to use the second booster in case of failure of the one in use.

1E. The Switches for Closing the Generator Field Circuits.—These switches are mounted at the top of the center panel and are opened and closed electrically. In case of emergency they may also be opened and closed by hand. They consist simply of two arms, moved together by solenoids, which, in closing, make two contacts each, in succession. The first is an auxiliary contact (the tips of which are readily replacable), and is designed to close before and open after the second contact. The second contact is the main one and carries the current when the arms are closed, the auxiliary contact being intended to take any arcs that occur in closing or opening, and so protect the main contacts. Diagram 5 gives a rough representation of the idea outlined, although the mechanical means of carrying out the idea is different in the switches installed. In 5*a*, the switch is partly closed, the auxiliary contacts being

in contact, but the main ones open. The switch is entirely closed in 5*b*. On opening the switch the main contacts open first as in 5*a*. Contacts A and B are joined on the face of the switch in practice.

Electrically these switches have a closing and a tripping coil. When the closing coil is energized from the main board, a closing plunger is lifted, which closes the switch sharply against a spring. The switch is held closed by a latch. When it is desired to open the switch the tripping coil is energized, which lifts a plunger and knocks out the latch. The switch is closed by hand, if desired, by a lever which lifts the closing plunger and it is opened by hand by lifting the same plunger which the tripping coil operates, and knocking the latch.

As said before, the field switches are equipped with a number of auxiliary switches and interlocks. It is highly essential that the field switches are not closed unless the booster is running. Referring to diagram 1, suppose switches K and N closed and L thrown up. If the field switches were now closed, generator field current at a value of about 500 ampères would flow through the booster armature, which would make it run away. In order to prevent this, the field switches are interlocked with the booster motor "pump" (starting) switch, so that the starting switch must be closed before the field switches *can* be closed. Conversely, the field switches must be opened before the starting switch can be pulled.

On either side of the field switches are two buttons 1 and 4, diagram 6*a*, which the field switches in closing, press into the board. The buttons normally are held out by springs. Button 1 is interlocked with a similar button, 2, closed by the booster motor "pump" (starting switch), in such a way that button 1 will not depress until button 2 is in. If button 1 does not depress, the field switches cannot close. This makes it necessary to start up the booster motor before attempting to operate the field switches.

Button 1 is also interlocked with a latch 3, over the handle of the "pump" switch. As button 1 moves into the board, latch 3 moves down, gripping the handle of the "pump" switch and locking it in. Latch 3 does not release the "pump" switch until button 1 is out again, which means that the field switches are open. Button 4 in closing actuates a switch in back of the board, which closes the circuits of the interlocks, locking all apparatus on the main board that must not be changed while the field switches are in. This switch is in back of the exciter board and also operates the indicating lights on the exciter and main switchboards.

The field switches are also each equipped with an auxiliary contact 5, which is opened when the field switches close and is closed as soon as they start to open. It simply connects a resistance across the alternator field, as outlined in diagram 6*a*, to take the inductive discharge from the field and reduce the arc at the contacts of the field switches, on opening.

It will readily be realized that although the position of the "pump" switch is made certain of, the operator could, by thoughtlessly opening switches K, M, L or N, cause much trouble. The significance of the red color of the handles of the switches of the booster set is thus the more apparent.

Should it become necessary to cut out the booster at any time before the field switches are first opened, switch L is thrown down and switches M and N opened, the latter disconnecting both booster motor and generator from the negative side of the "Auxiliary" bus. The "pump" switch must, however, be left closed, on account of the interlocks to the field switches.

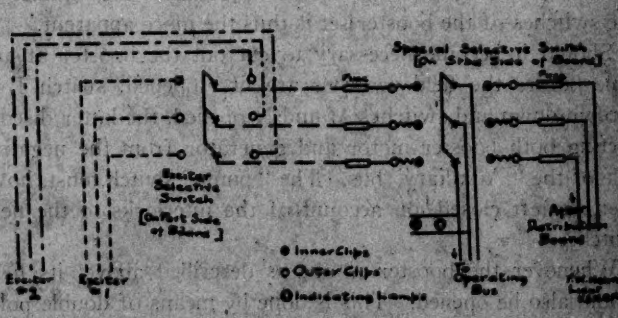
Whenever the booster is out as described above, its field should also be opened. This is done by means of double pole, single-throw knife switches (one for each booster) mounted on a small separate panel, over the main operating board, on a level with the exciter switchboard platform.

rF. The Selective Switches for Energizing the Operating Bus.—To derive voltage for supplying the booster field cur-

rents as well as for operating the various interlocks, relays, indicating lamps, field switches, etc., a set of busses on the main switchboard are provided. These busses are called the "Operating" busses and must always be energized. In order to provide for any emergency, they may be energized from either exciter or from the after distribution board. To get this amount of selection, two triple-pole, double-throw switches are provided, one each on the bottom of the outboard panels. The one on the starboard side is a special switch, built as shown in diagram 7, having two sets of clips. The outer clips are of the regular type, but the inner ones are special, curving around as shown. When the blades are as shown in the "top" view, they make contact with both sets of inner clips. If the blades are thrown over to one side, they continue to make contact with the inner clips until after they go into contact with the outer ones. The other switch, mounted on the port side, is of the ordinary type of knife switch.

In diagram 8 is shown the scheme of wiring somewhat re-

Diagram 8



arranged. A set of taps are taken from each "Exciter" bus to the two sets of clips of the port switch. From the blades of the port switch, leads go to the inboard clips of the starboard or special switch. The outboard clips of this switch are

Illuminating
Lamps
To Alternator Field
Field Rheostat
To Armature on A.C. Boards
To Field Rheostat on A.C. Boards
Starting Resistance
Starboard Auxiliaries, Booster Circuits etc not shown.
Visible Lamps
To Starboard Auxiliaries
To Engine Circuit Breaker
To Operating Bus
To Aft Distribution Room
Stbd. Exciter
Aft Exciter

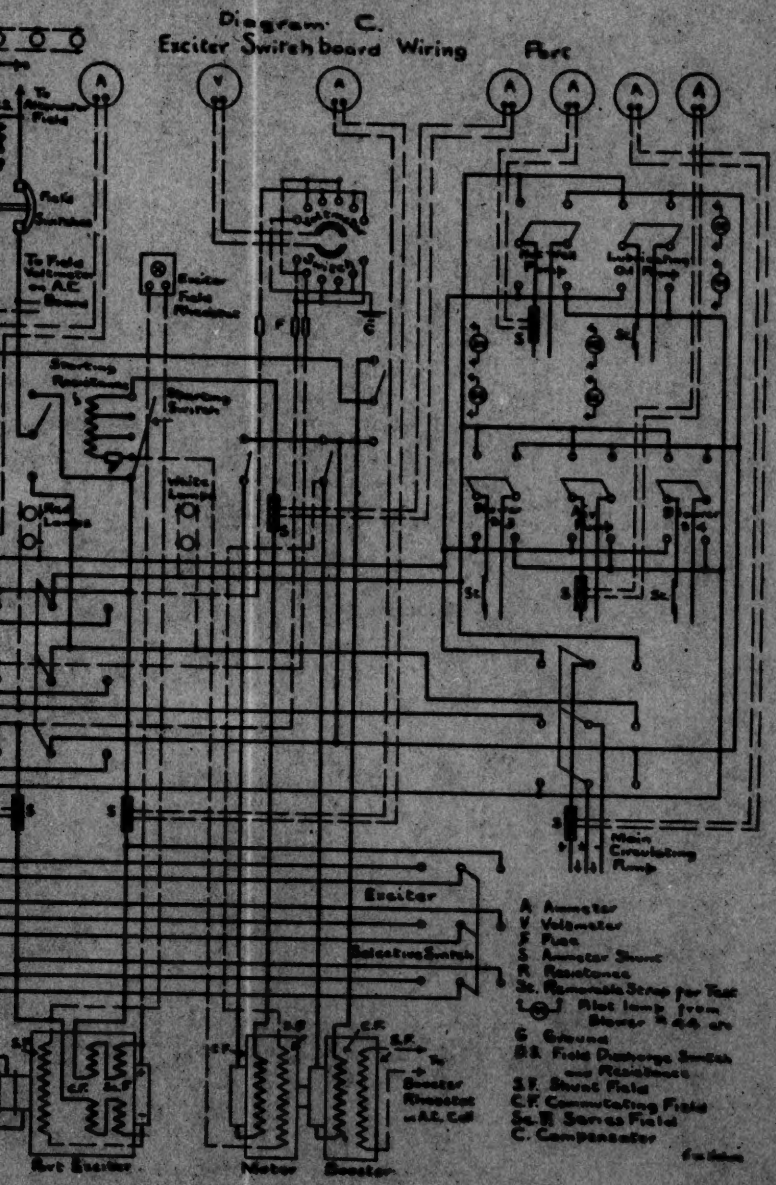


Diagram C.
Exciter Switchboard Wiring Part
Exciter
Selective Switch
Main Circulating Pump
A Ammeter
V Voltmeter
F Fuse
S Ammeter Shunt
R Resistance
Sc. Removable Strap for Test
Pilot lamp from Blower to 44 a/c
G Ground
DS Field Discharge Switch and Resistance
S.F. Shunt Field
C.F. Commutating Field
Se.F. Series Field
C. Compensator
Booster Rheostat in A.C. Coil
Part Exciter
Motor
Booster

connected to the "After" distribution feeders. From the blades of the special switch, leads go directly to the "Operating" bus. The pilot lamps shown in the diagram serve to warn the operators and are mounted at the top of the exciter and main switchboards. They burn as long as the "Operating" bus is alive.

Normally, the "Operating" bus is energized from one of the exciters, but if it is desired to throw it over on the other exciter, the special switch is first thrown over to the after distribution board, the port switch thrown over to the other exciter and the special switch thrown back. It will be seen that, by reason of the inner clips of the special switch, potential is never taken off the "Operating" bus during the switching. When the blades of the special switch are spanning both sets of inner clips, current is taken from both sides. Should there be any difference of potential between the two sources (exciters and after distribution board), a short circuit current would flow from one source to the other, were it not for the fact that limiting resistances are put into circuit between the inner and outer clips on each side. These are shown in diagram 8. They will carry the full control current as well as any short circuit current that might be caused, if the latter is not excessive. If it is excessive the fuses will blow. An excessive current would flow only if the "Operating" bus were thrown on a dead exciter or one whose voltage was very low. Besides, whenever the special switch is operated, it is thrown over very rapidly. It is of course evident that if both exciters are out of commission, the "Operating" bus can be energized from the after distribution board by leaving the special switch thrown outboard.

2. THE ALTERNATING CURRENT WIRING.

A. The Power Wiring and Switches between Generators and Motors:

a. The Bus Tie Switch.

b. The Motor Reversing Switches.

c. The Motor Disconnecting Switches.
d. The Generator Disconnecting Switches.
e. The Motor Pole Changing Switches.

B. Wiring for Meters, Balanced Relays, etc.

2A. Diagram 11 shows the complete a.c. wiring on the port side.—As there indicated, power is generated in the generators and transmitted to the motors as a two-phase, four-wire system. The chief reason for adopting a two-phase system instead of three-phase, as will be used on some newer ships, is that one motor stator winding, which can be arranged for either 24 or 36 poles with all conductors active in either combination, is feasible with two phase, but difficult with three phase. Where the three-phase system has been adopted, two separate motor stator windings, one giving 24 and the other 36 poles, are necessary. Further, two different easily made arrangements of the two-phase generator armature windings, give, for the same field current and speed, values of voltage in the ratio of 100 to 141.

The generator disconnecting switches, at the top of diagram 11, are heavy knife switches, operated by long levers and located on the outboard bulkheads of the center engine room, abreast of the main operating board. In their open or neutral position, they disconnect the generator from the rest of the system while if closed either way, they connect the generator and arrange the generator armature windings in one of two combinations.

There are four parts to the winding of the generators, which are brought to the disconnecting switches on eight cables. Arranged one way by the generator disconnecting switches results in the so-called "low voltage" combination of the winding. Arranged the second way, gives a voltage 41 per cent greater, this combination being known as the "high" voltage arrangement. This will be taken up in further detail in 2*Ad*.

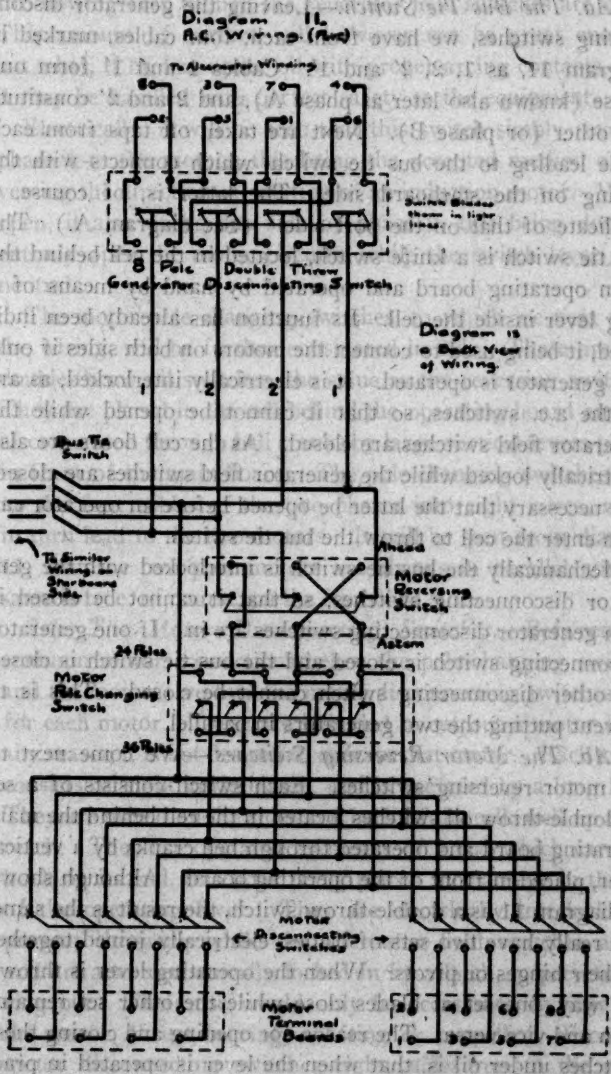


Diagram 11.
A.C. Wiring. (Aft)
To Alternator Windings
8 Pole Double Throw
Generator Disconnecting Switch
Diagram is a Back View of Wiring.
Bus Tie Switch
To Similar Wiring on Starboard Side
Ahead
Motor Reversing Switch
Astern
24 Poles
Motor Pole Changing Switch
36 Poles
Motor Disconnecting Switches
Motor Terminal Boards

2Aa. The Bus Tie Switch.—Leaving the generator disconnecting switches, we have from each, four cables, marked in diagram 11, as 1, 2, 2′ and 1′. Cables 1 and 1′ form one phase (known also later as phase A), and 2 and 2′ constitute the other (or phase B). Next are taken off taps from each cable leading to the bus tie switch, which connects with the wiring on the starboard side. The latter is, of course, a duplicate of that on the port side. (See diagram A.) The bus tie switch is a knife switch, located in the cell behind the main operating board and operated by hand by means of a long lever inside the cell. Its function has already been indicated, it being used to connect the motors on both sides if only one generator is operated. It is electrically interlocked, as are all the a.c. switches, so that it cannot be opened while the generator field switches are closed. As the cell doors are also electrically locked while the generator field switches are closed, it is necessary that the latter be opened before an operator can even enter the cell to throw the bus tie switch.

Mechanically the bus tie switch is interlocked with the generator disconnecting switches, so that it cannot be closed if both generator disconnecting switches are in. If one generator disconnecting switch is closed and the bus tie switch is closed the other disconnecting switch cannot be closed. This is to prevent putting the two generators in parallel.

2Ab. The Motor Reversing Switches.—We come next to the motor reversing switches. Each switch consists of a set of double-throw oil switches located in the cell behind the main operating board and operated through bell cranks by a vertical lever, placed in front of the operating board. Although shown in diagram 11 as a double-throw switch, the result is the same. We really have two sets of blades, electrically joined together at their hinges or pivots. When the operating lever is thrown one way, one set of blades close while the other set remains open and vice versa. The reason for opening and closing these switches under oil is, that when the lever is operated in practice there will probably be some fraction of the load current

still flowing even though the generator field switches are open. This amount of current will however not be great enough, but what, if broken under oil with proper arcing contacts, etc., it may be handled with perfect safety to the equipment.

Electrically, it will be seen that this switch simply reverses phase 1 to the motors, this being the accepted method of reversing the direction of rotation of an induction motor. While open, it also opens one side of phase 2, this being done to entirely open the motor circuits, while the switch lever is in neutral.

The motor pole changing switches, to which we next trace the wiring, will be further considered in 2*Ae*. These are also double-throw oil switches, the same as the reversing switches. They are placed in the cell behind the operating board and are also operated through bell cranks by large vertical levers placed in front of the main board. The pole-changing switches split up the four cables of the two phases into eight wires, which in turn lead to the two motors. It will be seen from diagram 11, that the two port motors are always in parallel and the same is true, of course, on the starboard side.

2Ac. The Motor Disconnecting Switches.—Between the common motor connections below the pole-changing switches and the motors, we find the motor disconnecting switches, one for each motor. These are intended to cut out a motor if for any reason it is not desired to operate that motor. Each switch consists of eight knife blades, and is operated by a long lever. They are placed on the sides and back of the cell, well up above reach. They are operated by means of a rod which carries a hook on its end, this hook being placed into an eye in the end of the operating lever. They are electrically interlocked to prevent throwing while the alternator field switches are in and are also mechanically locked in by a latch, to prevent jarring out. Their use would only be occasioned by injury to the motor, thrust bearing, shafting or propeller. From the motor disconnecting switches eight cables run to the motor terminal boards.

2Ad. The Generator Disconnecting Switches.—To study the action of these switches in arranging the generator winding, diagrams 12 and 13 are provided. The generator armature winding is in four parts, the ends of which are numbered 1′5′, 2′6′, 3′7′ and 4′8′, connected, respectively, to terminals 1, 5, 2, 6, 3, 7, 4 and 8 on the terminal boards. Throughout diagrams 12 and 13, the cables of phase 1 are shown solid and those of phase 2 are broken. In the switch the blades are represented by arcs, thrown up in diagram 12*a*. It will be seen that the blades are electrically connected at their hinges in pairs and from this connection are led off the leads going to the motor switches. These common points are designated *a a′* for phase 1 and *b b′* for phase 2. In diagram 12*b*, is given a simplified view of the result of throwing the switches up. Starting in that diagram from *a*, we go to both 2′ and 8′, through their respective parts of the winding, to 6′ and 4′ and uniting at *a′*. This places these two parts of the alternator winding in parallel, so that the voltage of the combination is the same as the voltage of either part. Similarly for phase 2 we start at *b*, pass to both 5′ and 3′, through the windings to 1′ and 7′, uniting the two circuits again at *b′*. Considering diagram 12*a*, starting from *a*, we have for one of the two parallel circuits of phase 1, *a* to *e*, to 2, to 2′, to 6′, to 6, to *k*, to *a′*, and for the other circuit of the same phase, *a* to *f*, to 8, to 8′, to 4′, to 4, to *l*, to *a′*. The first of the two circuits of phase 2 is, *b*, *g*, 5, 5′, 1′ 1, *i*, *b′*, and the second is, *b*, *h*, 3, 3′, 7′, 7, *j*, *b′*. The circuits indicated by the light broken lines, *m e*, *f r*, etc., are not used when the switch is thrown up.

If now the switches are thrown down, the result is shown in diagram 13. We have now put the four parts of the generator winding into what is called a mesh connection, simply shown in diagram 13*c*. With the windings of a two-phase generator so connected we obtain one phase by tapping two diagonal corners and the other phase, by connecting to the other two diagonal corners. The corners *a* and *a′*, in diagram 13*c* give phase 1 and corners *b* and *b′* give phase 2. Diagram

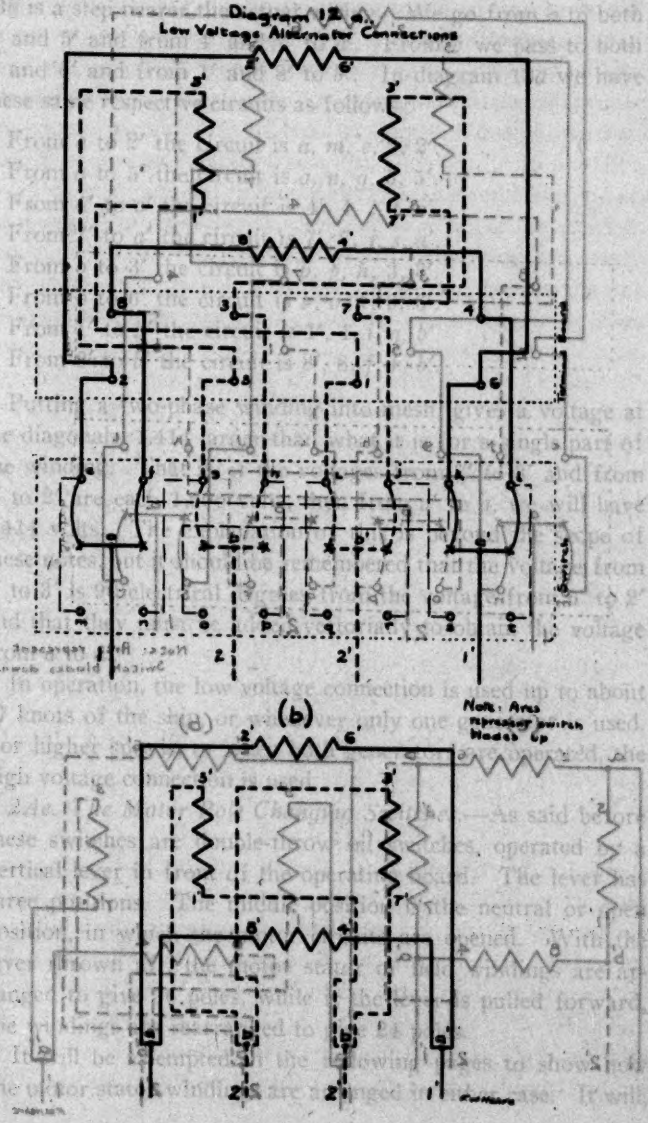
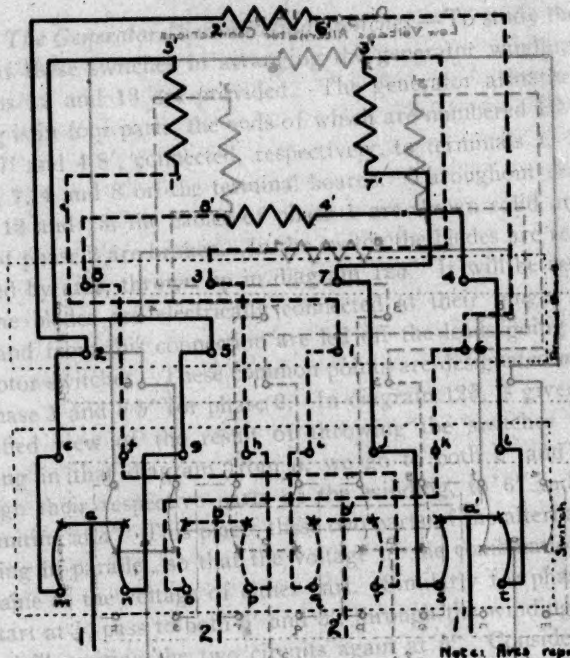
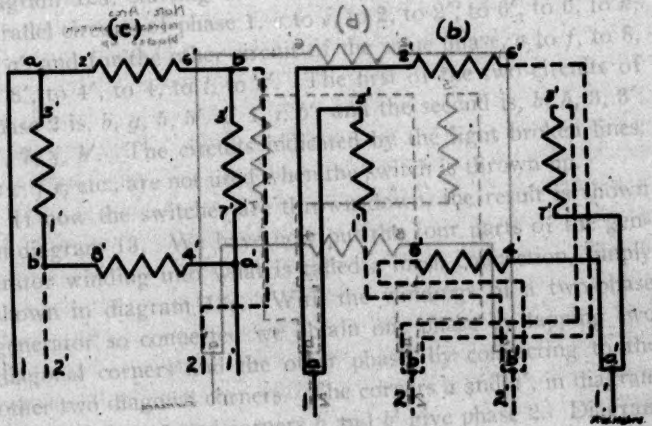


Diagram 12 a.
Low Voltage Alternator Connections
(b)
Note: Arcs represent switch blades up

Diagram 13 a.

High Voltage Alternator Connections





13*b* is a step nearer the actual wiring. We go from *a* to both 2′ and 5′ and from 4′ and 7′ to *a*′. From *b* we pass to both 3′ and 6′ and from 1′ and 8′ to *b*′. In diagram 13*a* we have these same respective circuits as follows:

From *a* to 2′ the circuit is *a*, *m*, *e*, 2, 2′.
From *a* to 5′ the circuit is *a*, *n*, *g*, 5, 5′.
From 4′ to *a*′ the circuit is 4′, 4, *l*, *t*, *a*′.
From 7′ to *a*′ the circuit is 7′, 7, *j*, *s*, *a*′.
From *b* to 3′ the circuit is *b*, *p*, *h*, 3, 3′.
From *b* to 6′ the circuit is *b*, *o*, *k*, 6, 6′.
From 1′ to *b*′ the circuit is 1′, 1, *i*, *q*, *b*′.
From 8′ to *b*′ the circuit is 8′, 8, *f*, *r*, *b*′.

Putting a two-phase winding into mesh, gives a voltage at the diagonals, 1.414 larger than what it is for a single part of the winding. That is, if the voltages from 7′ to 3′ and from 6′ to 2′ are each 1,000 volts, then from *a*′ to *a*, we will have 1,414 volts. The explanation of this is beyond the scope of these notes, but it should be remembered that the voltage from 7′ to 3′ is 90 electrical degrees from the voltage from 6′ to 2′ and that they must be added vectorially to obtain the voltage from *a* to *a*′.

In operation, the low voltage connection is used up to about 17 knots of the ship, or whenever only one generator is used. For higher speeds, or when both generators are operated, the high voltage connection is used.

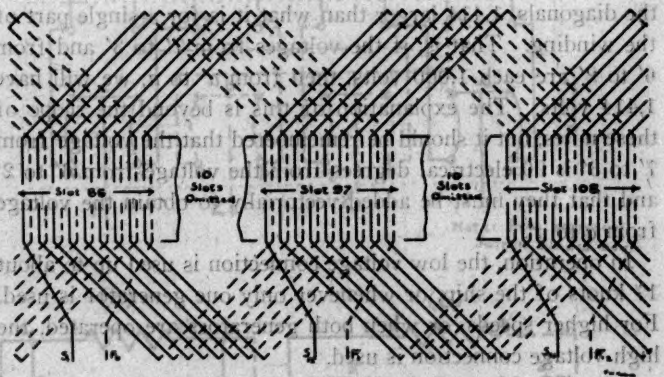
2Ae. The Motor Pole Changing Switches.—As said before these switches are double-throw oil switches, operated by a vertical lever in front of the operating board. The lever has three positions. The middle position is the neutral or open position, in which the motor circuits are opened. With the lever thrown aft, the motor stator or field windings are arranged to give 36 poles, while if the lever is pulled forward, the windings are rearranged to give 24 poles.

It will be attempted in the following pages to show how the motor stator windings are arranged in either case. It will,

however, first be necessary to investigate the motor windings to some extent. There are 384 slots in the stators of the motors and in these 384 slots there are placed 384 coils. In each slot there are therefore two coil sides; that is, the right hand side of one coil and the left hand side of another. The same coil side of all the coils are placed at the bottom of the slots and all the other coil sides are placed at the top.

Each coil has 9 turns in series as is shown in diagram 14. Here are represented three slots, numbers 86, 97, and 108, the intervening ones being omitted. A coil starts, let us say, at S_1 at the front end, passes through slot 86 to the back of

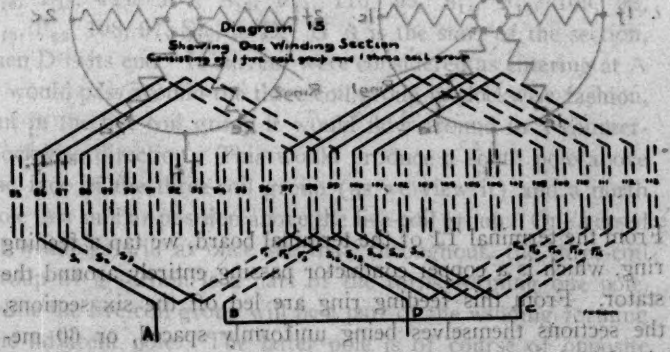
Diagram 14
Showing Full Coils



the stator, along the back to slot 97 and forward again, completing one turn. After leaving slot 97 the wire again passes back to slot 86 and around as before, continuing this until nine turns have been completed. The end of the coil is then F_1. As shown, the left hand conductor of each turn is drawn in full lines, while the right hand ones are in broken lines. Actually, as in all electrical machinery, these coils were wound on a form, properly insulated and shaped and then treated with

proper insulating compounds to guard against moisture, and baked. After this treatment they were inserted in the slots. All the conductors represented by the full lines in any slot are all together in one bundle and the same for the conductors represented by the broken lines. As inserted in the slots, one bundle then lies above the other.

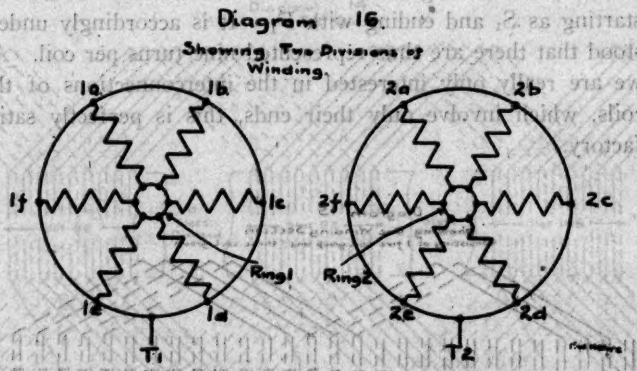
In the diagrams used in this discussion to show the connections as made by the pole-changing switches, it was thought advisable to represent over 100 slots. To have represented each slot completely as in diagram 14, would have made a confusing diagram, out of all proportions, so that, as is often done in such diagrams, each coil is represented as a single turn. We have then in diagram 15 the coil inserted in slots 86 and 97, starting as S_1 and ending with F_1. It is accordingly understood that there are thus represented nine turns per coil. As we are really only interested in the interconnections of the coils, which involve only their ends, this is perfectly satisfactory.



In diagram 15, the interconnections are indicated. The end of coil 86-97, which is marked F_1, is joined to the Start (S_2) of the next coil, 87-98, and so on, as many coils being joined in series as the design warrants.

The entire winding of 384 coils is divided into 8 divisions. Each division starts at one of the eight terminals of the motor terminal boards, being fed by one of the eight cables leading from the pole changing switches and ends at either one of two "rings," within the motors. These two "rings" are large copper conductors, bent into the form of a ring, closed upon themselves and placed at one end of the windings, just beyond the end connections of the coils. Their function will appear later.

In diagram 16 are represented two of these winding divisions. Each division consists of six sections placed in parallel.



From the terminal T1 of the terminal board, we tap a feeding ring, which is a copper conductor passing entirely around the stator. From this feeding ring are led off the six sections, the sections themselves being uniformly spaced, or 60 mechanical degrees apart around the entire stator winding. The six divisions after passing through the coils again unite, all being tapped into ring 1, referred to above. The sections of division 2 have their own feeding ring and tap into a second ring, marked 2. The other divisions are all similar, each has its own feeding ring and the sections of each are uniformly

spaced around the stator. But it will be seen later that divisions 1, 3, 4 and 6 all tap into ring 1 and the other divisions, 2, 5, 7 and 8, all tap into ring 2.

Each section of a division consists of two groups of coils, a group of five coils and a group of three coils. In half of the total sections in the winding the three-coil group is to the left of the five-coil group as in diagram 15, while in the other half of the sections the three-coil group is on the right hand side of the five-coil group. But in either case they are similarly placed. An idea of the second arrangement may be obtained by looking at diagram 15 upside down.

Let us trace through the section shown in diagram 15: Starting at A, we pass to S_1, slot 86, slot 97, F_1, S_2, slot 87, slot 98, F_2, S_3, 88, 99, F_3, to B. B is the end of the three-coil group and this is connected to C, which, as we have so far been thinking, might be considered as the end of the five-coil group. This is correct and the reason for its being done will soon be apparent. From C we follow through F_{16}, slot 112, slot 101, S_{16}, F_{15}, 111, 100, S_{15}, F_{14}, 110, 99, S_{14}, F_{13}, 109, 98, S_{13}, F_{12}, 108, 97, S_{12}, to D. If A is the start of the section, then D is its end. If current were considered as entering at A it would pass around the three-coil group in clockwise fashion, but in the five-coil group it would flow around in a counter-clockwise direction. This would produce a south pole above the face of the three-coil group (as we view it) and a north pole in a similar position above the five-coil group. One versed in windings will at once see that, throughout, the three-coil group of a section is a part of the turns forming one pole, while the five-coil group will be a part of the winding forming the adjacent pole. The latter pole is of course of opposite polarity to the first.

We said before that the six sections of each of the eight winding divisions were uniformly spaced around the winding. Thus the combination of one section from each division will, in the 24-pole arrangement of the winding, account for four

poles and in the 36-pole arrangement will form 6 poles. There is, however, some overlapping of the divisions, as will be seen later.

Since the six sections of each division are all in parallel, we may represent each division by one section, for what is true of one section is true of all constituting a division. In diagram 17 the eight divisions are represented, each by a single section. In this and in subsequent diagrams, phase 1 or A is represented by broken lines and phase 2 or B by solid lines. This is done to make it easier to follow the diagrams and to distinguish between the two phases. The pole changing switch is thrown up (the blades of the switch being represented by arcs), arranging the winding to give 24 poles. The outer ends of each division are marked with a primed number (2′, 6′, etc.), corresponding to the numbers of the terminals of the switch above, to which the sections are connected. The significance of the letters, A*a* +, B*b* —, etc., with which the coils are marked will be taken up later. It is suggested that no attention be paid to them until the explanation appears. Then on review their significance will be appreciated.

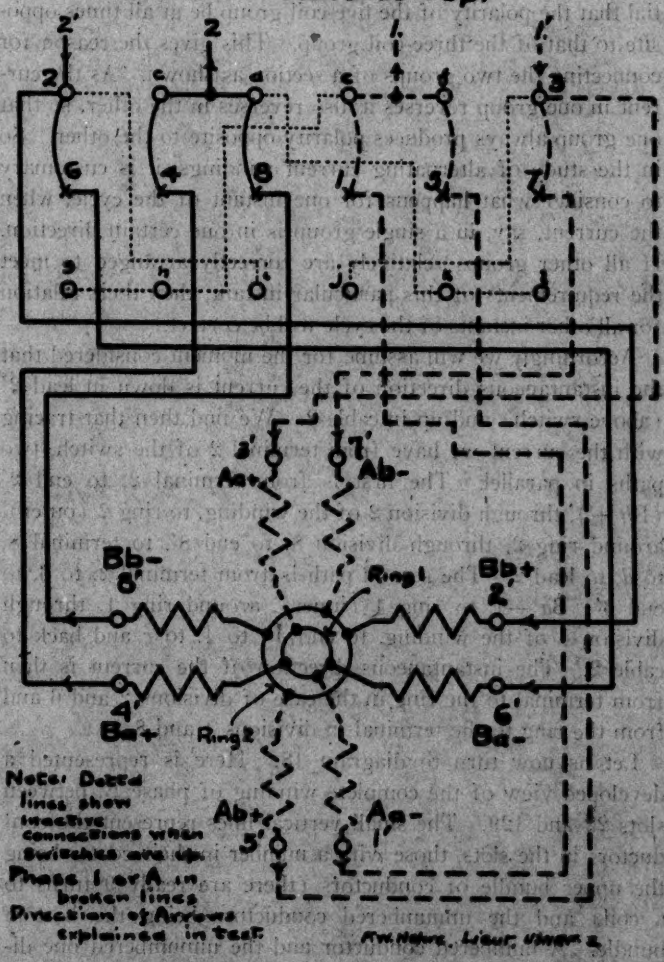
As stated before, divisions 2, 5, 8 and 7 will be found to be connected to the outer ring (No. 2) and divisions 6, 1, 4 and 3, to the inner ring (No. 1). The dotted interconnections of the switch (2 *i*, *g h*, *h e*, etc.) are inactive while the switch is thrown up. Although perhaps needless to mention, the fact should be carefully noted, that all the connections shown in diagram 17 and as well in diagram 20, which will show the switch thrown down arranging the winding for 36 poles, are all permanent. The mere act of throwing the switch one way or the other, makes the proper combination of the winding. The connections of the different divisions of the windings to rings 1 and 2 are made inside of the motor and naturally cannot be changed.

In dealing with the magnetic effects of alternating currents we are ordinarily not interested with any immediate polarities produced. What we do concern ourselves with, are relative

Diagram 17

MOTOR POLE CHANGING SWITCH.
and CONNECTIONS TO MOTORS.

24 Pole Connection Switches Up.



polarities. In diagram 15, for instance, the passage of alternating current will at one instant produce, say, a north pole above the three-coil group and a half cycle later will produce a south pole in the same region. But in order that the desired results may be obtained in this particular winding, it is essential that the polarity of the five-coil group be at all times opposite to that of the three-coil group. This gives the reason for connecting the two groups of a section as shown. As the current in one group reverses it also reverses in the other, so that one group always produces polarity opposite to the other. So in the study of alternating current windings, it is customary to consider what happens for one instant of the cycle, when the current, say, in a single group is in one certain direction. If all other groups relatively are correctly arranged to meet the requirements of this particular instant, then their relation for all other instants of the cycle will be correct.

Accordingly we will assume for the moment considered that the instantaneous direction of the current is down in lead 2′ (above switch) and up in cable 2. We find then that tracing with the current we have from terminal 2 of the switch, two paths in parallel. The first is from terminal 2, to end 2′ (B*b* +), through division 2 of the winding, to ring 2 (outer), around ring 2, through division 8, to end 8′, to terminal 8, to *d*, to lead 2. The second path is from terminal 2, to 6, to end 6′ (B*a* —), to ring 1 (inner), around ring 1, through division 4 of the winding, to end 4′, to 4, to *c* and back to cable 2. The instantaneous direction of the current is then from terminal to the ring in the case of divisions 2 and 6 and from the ring to the terminal in divisions 4 and 8.

Let us now turn to diagram 18. Here is represented a developed view of the complete winding of phase B, between slots 22 and 129. The small vertical lines represent the conductors in the slots, those with a number in their center being the upper bundle of conductors (there are really 9 turns to a coil) and the unnumbered conductors being the bottom bundle. A numbered conductor and the unnumbered one di-

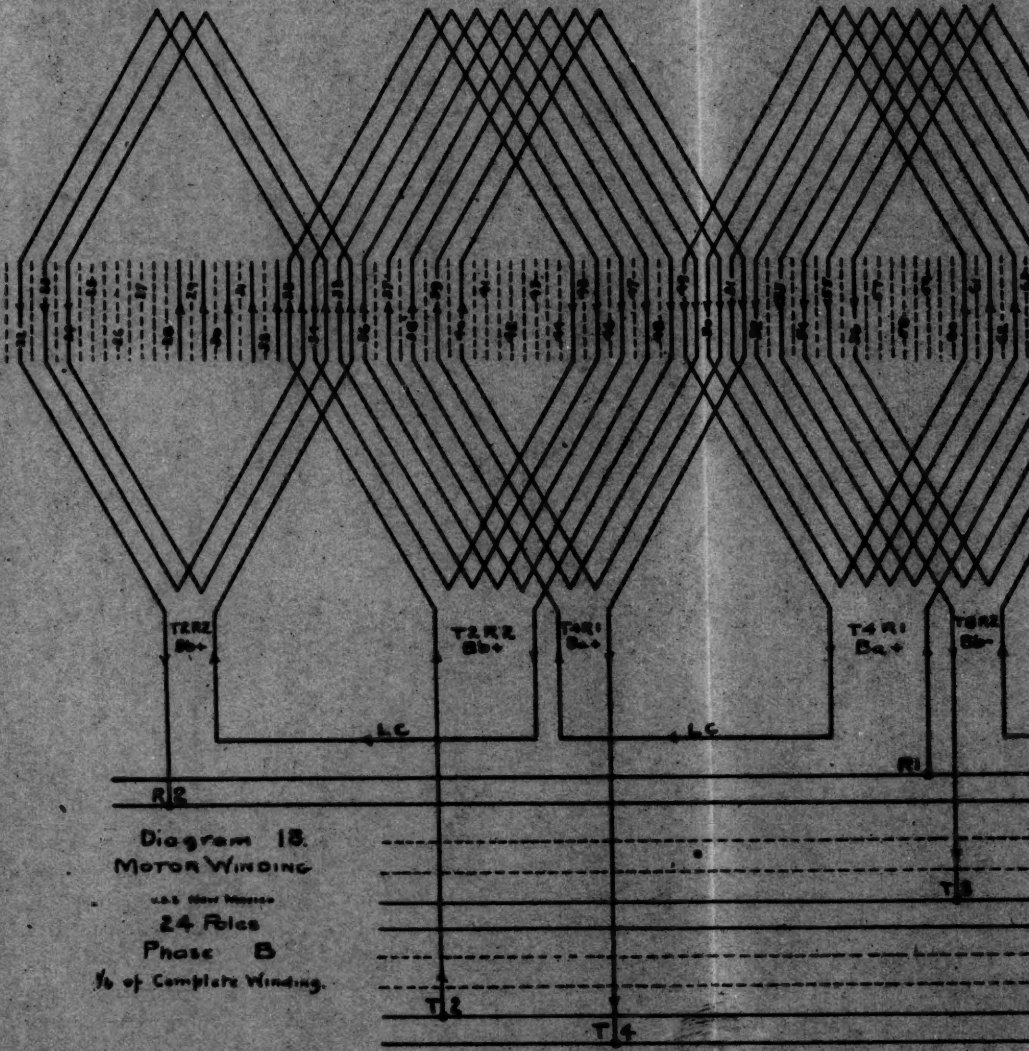
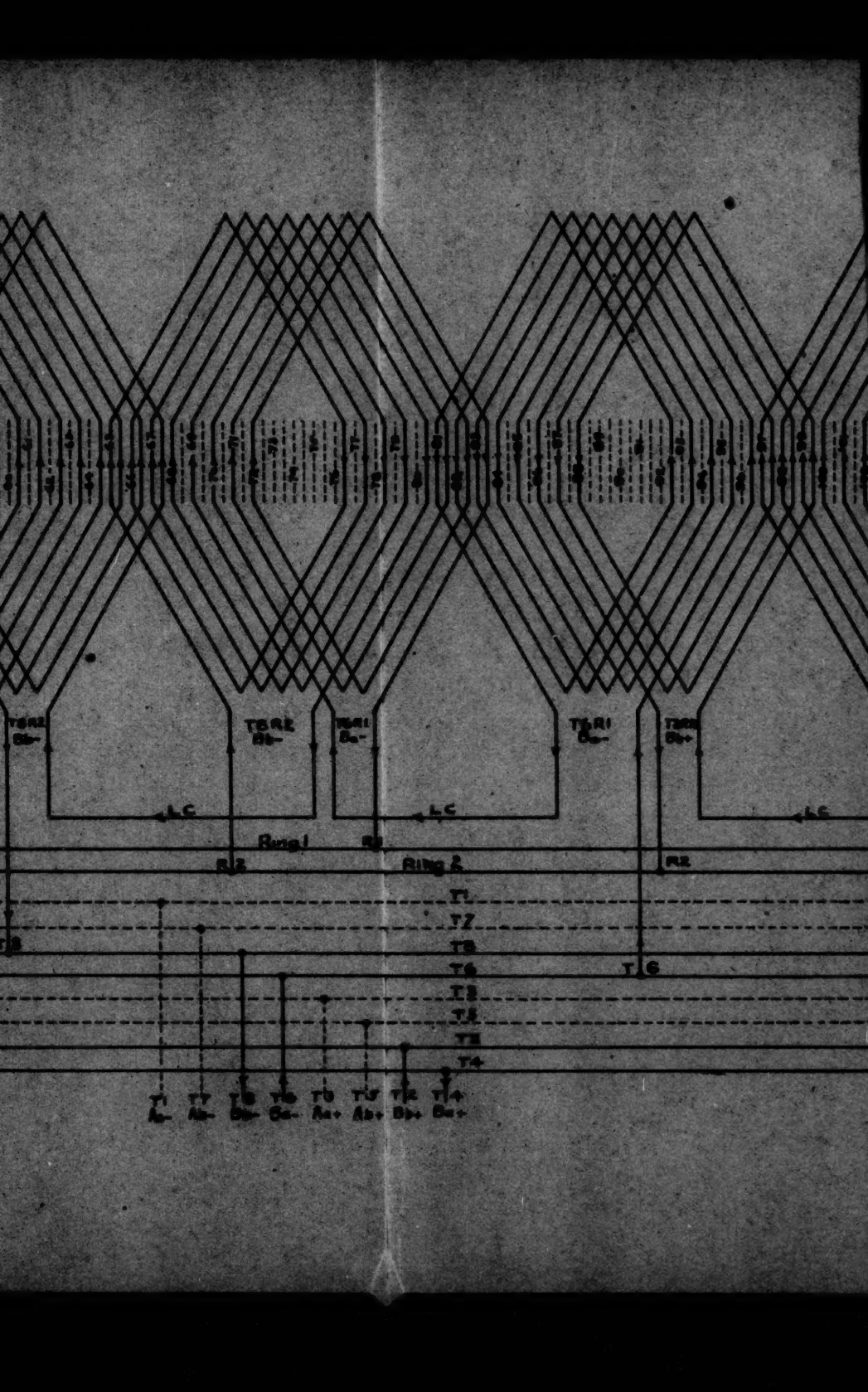
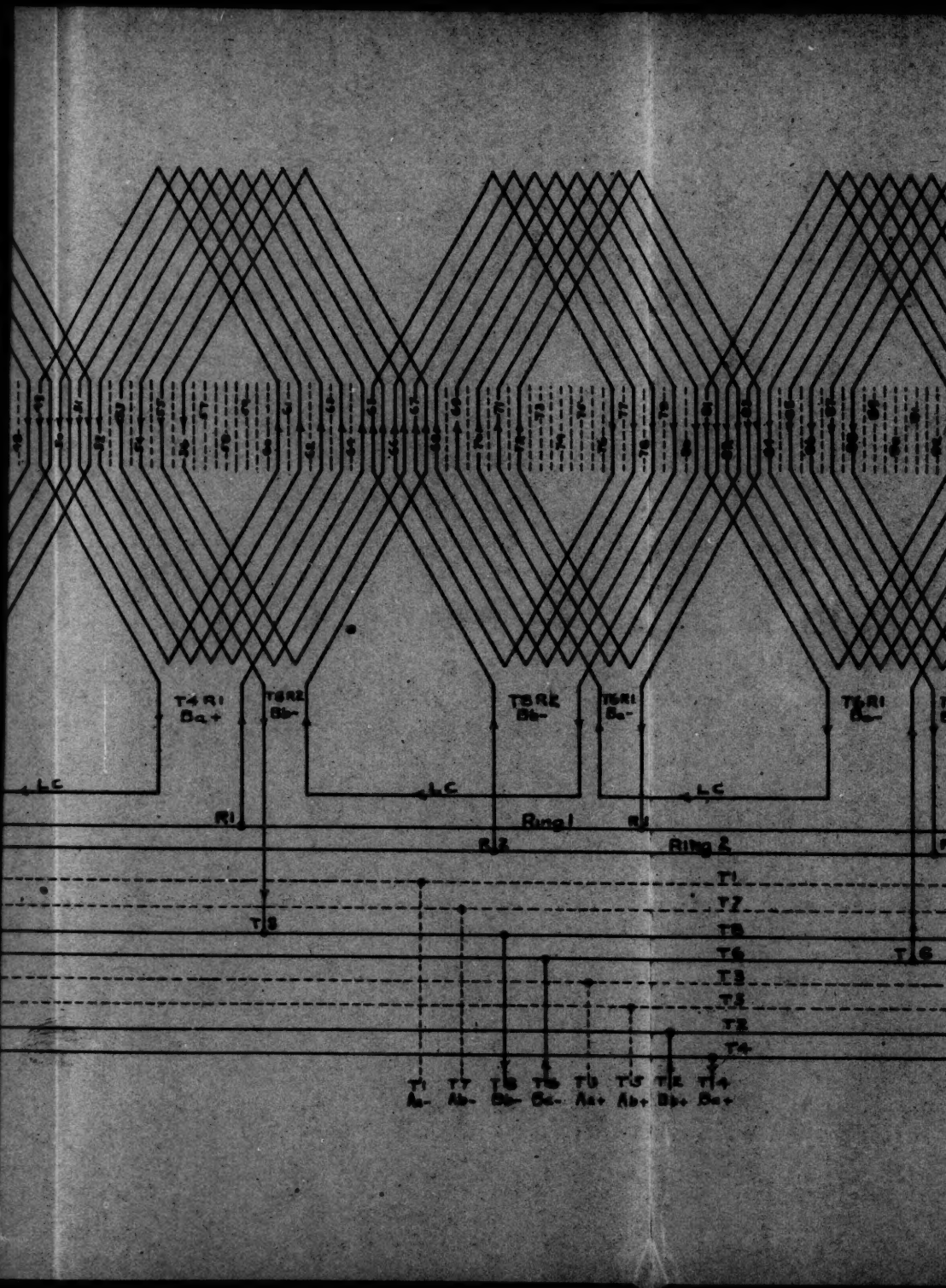
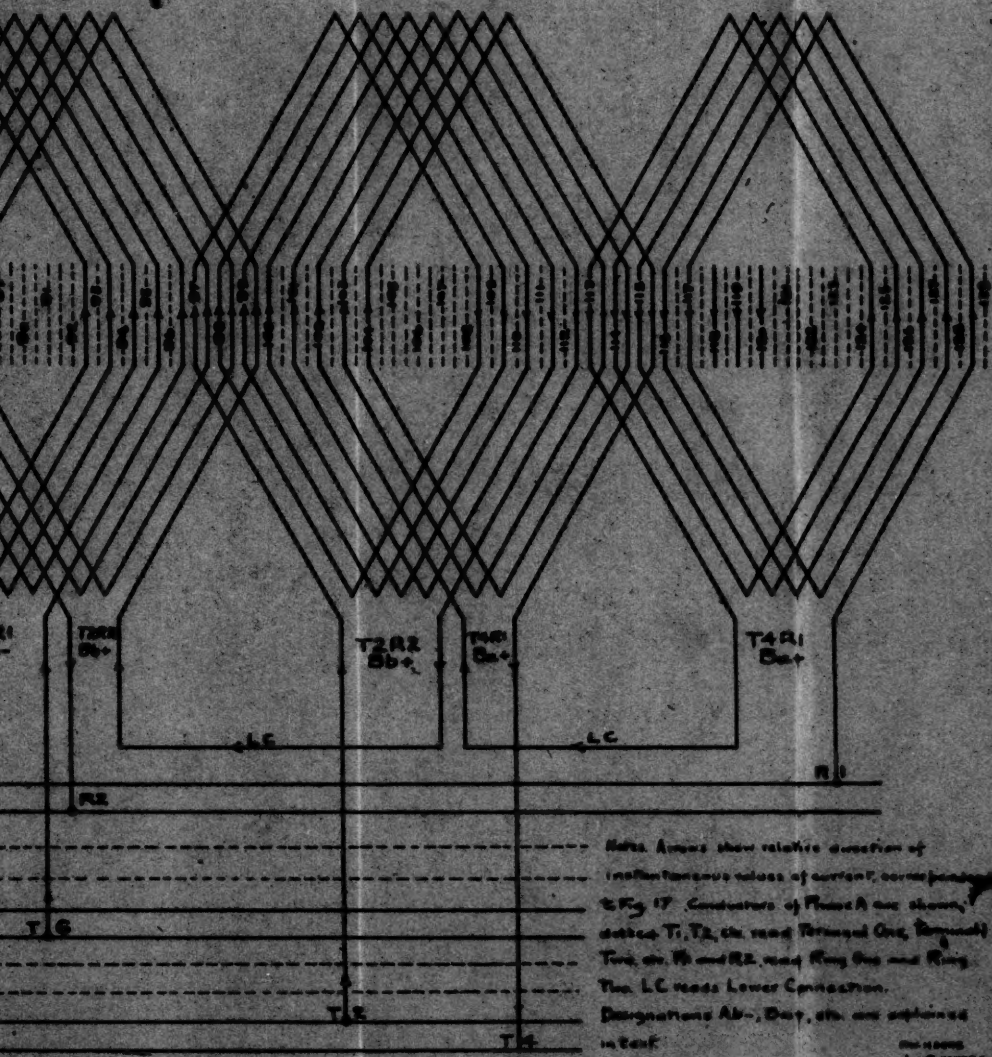


Diagram 18.
MOTOR WINDING
U.S. Slow Machine
24 Poles
Phase B
1/6 of Complete Winding.


T8R2 Bb-
T8R2 Bb-
T8R1 Ba-
T8R1 Ba-
T8R2 Bb+
LC
LC
LC
Ring1
R2
R2
Ring 2
R2
T1
T2
T3
T4
T5
T6
T7
T8
T6
T1 Aa-
T7 Ab-
T8 Bb-
T6 Ba-
T5 Aa+
T4 Ab+
T2 Bb+
T3 Ba+


T4 R1 Ba+
T8 R2 Bb-
T8 R2 Bb-
T8 R1 Ba-
T6 R1 Ba-
LC
LC
LC
R1
Ring1
R2
R1
Ring 2
T1
T2
T3
T4
T5
T6
T7
T8
T1 Aa-
T7 Ab-
T3 Bb-
T8 Ba-
T5 Aa+
T5 Ab+
T2 Bb+
T4 Ba+



Notes. Arrows show relative direction of instantaneous values of current, corresponding to Fig 17. Conductors of Phase A are shown; dotted: T1, T2, etc. read Terminal One, Terminal Two, etc. R1 and R2 read Ring One and Ring Two. LC reads Lower Connection. Designations Ab-, Ba+, etc. are explained in text.

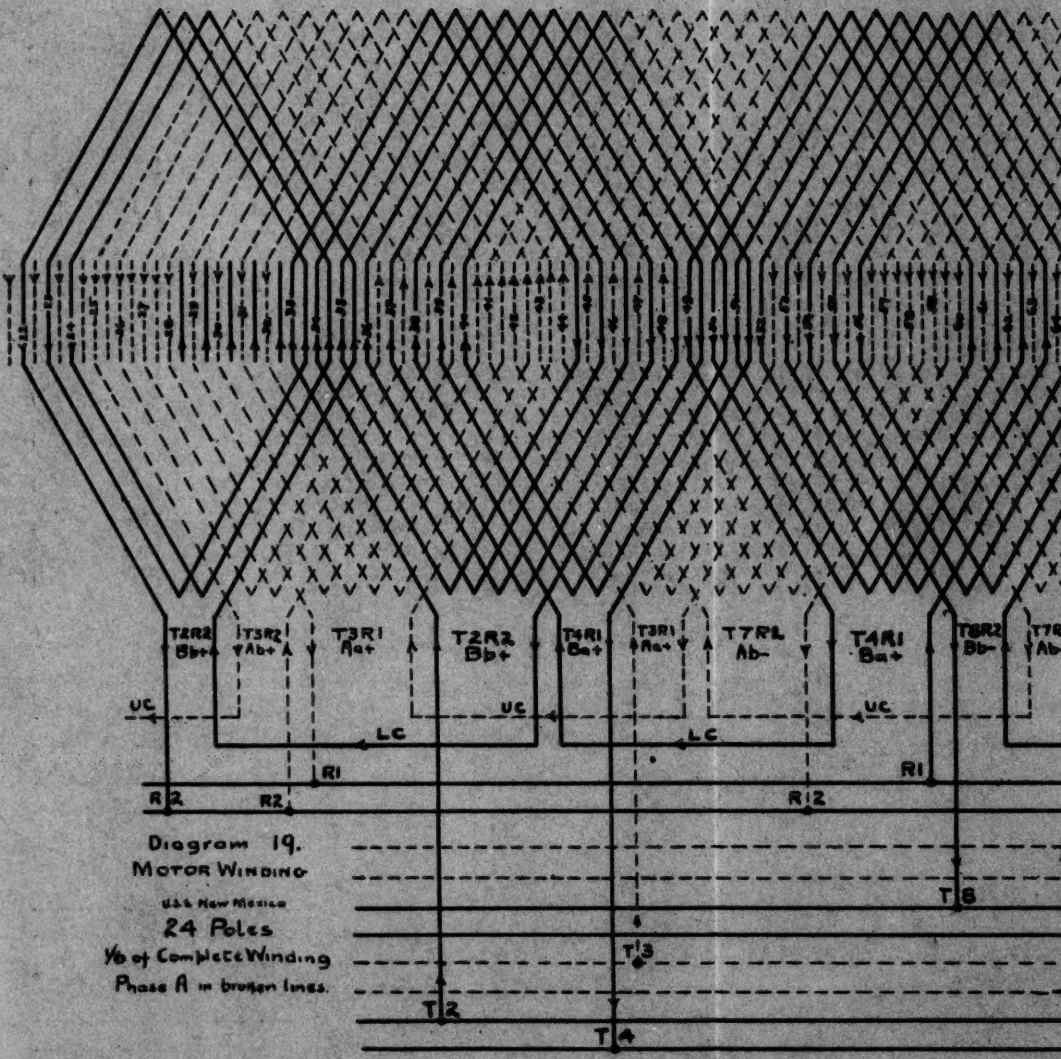
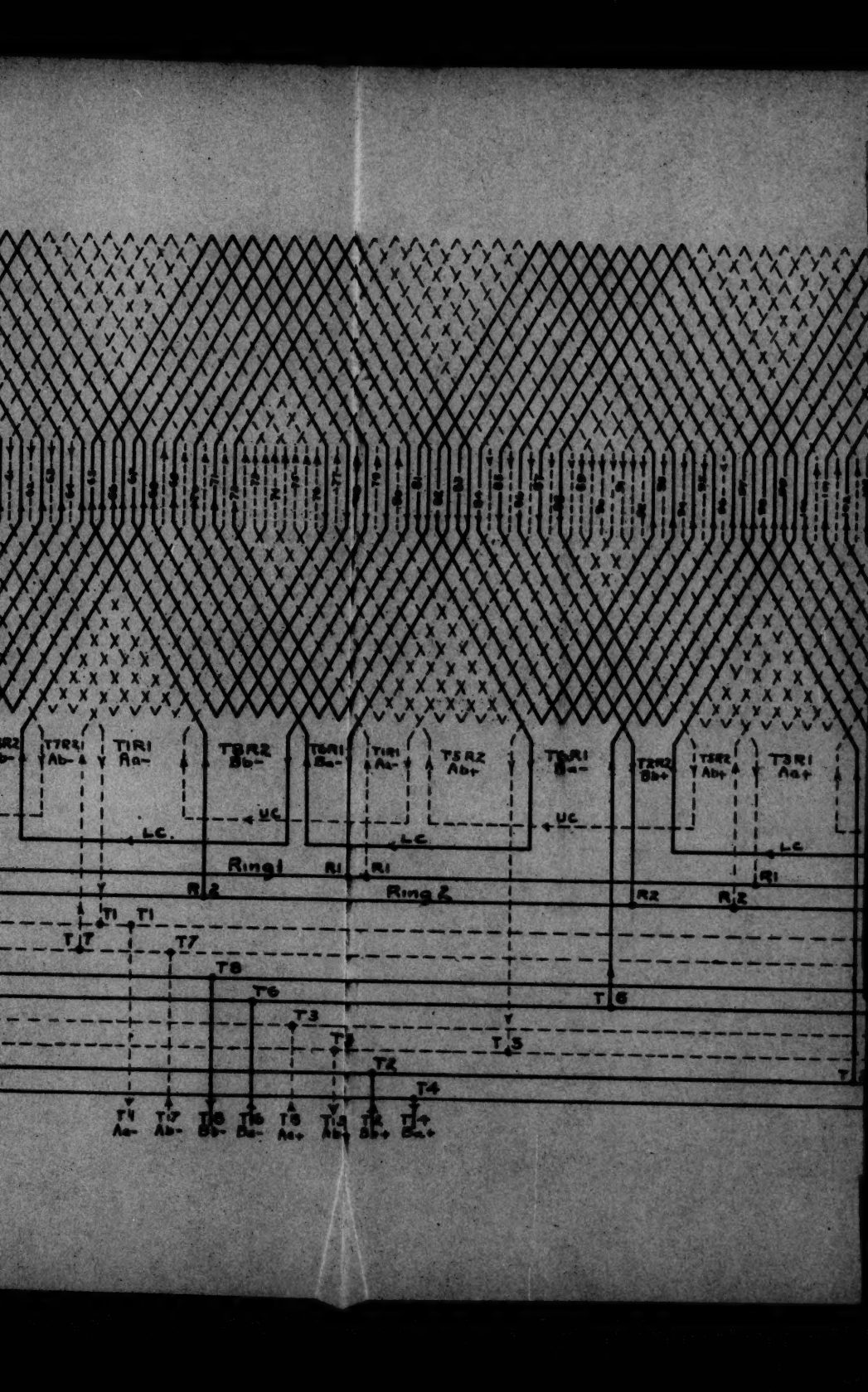
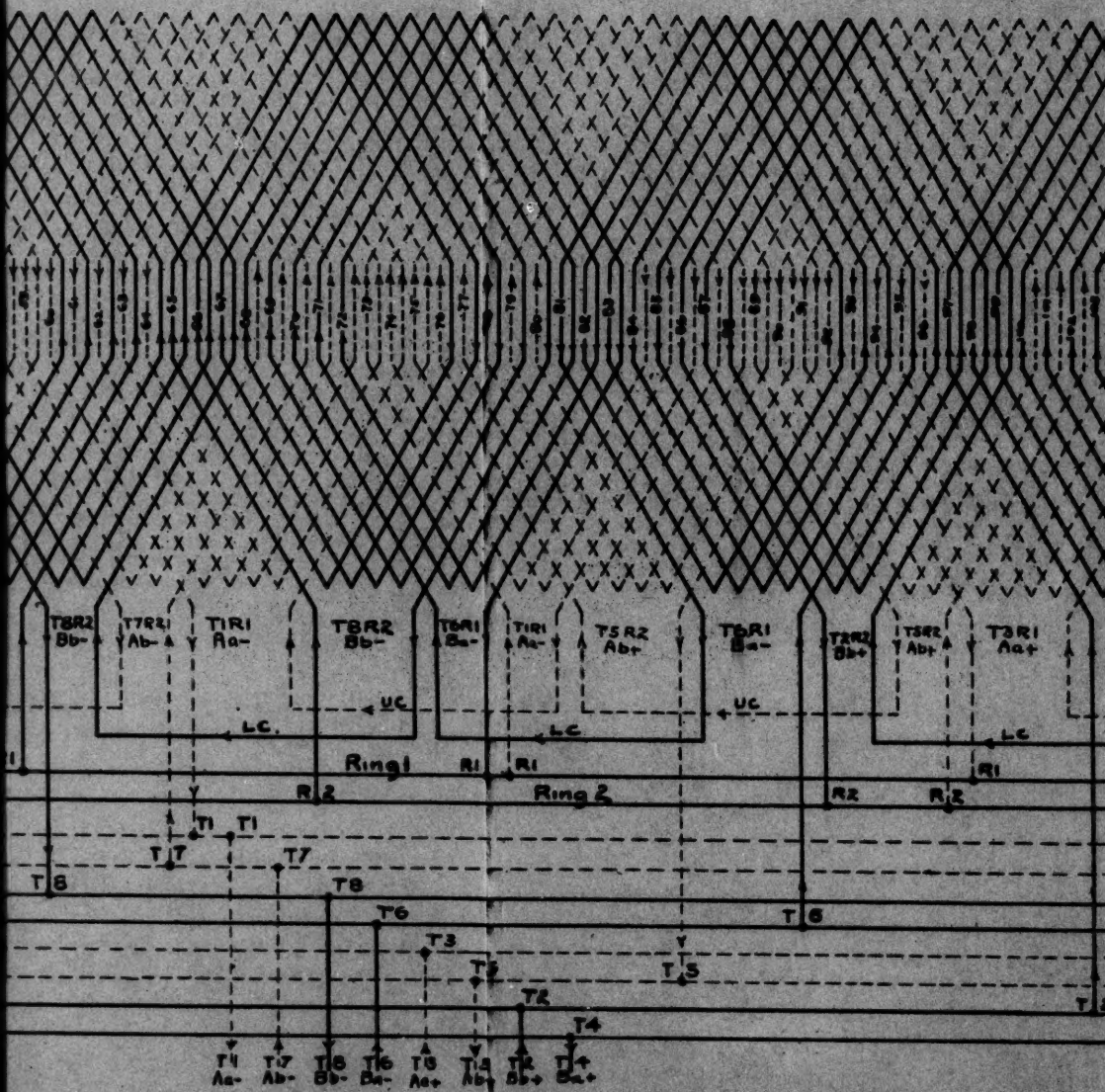
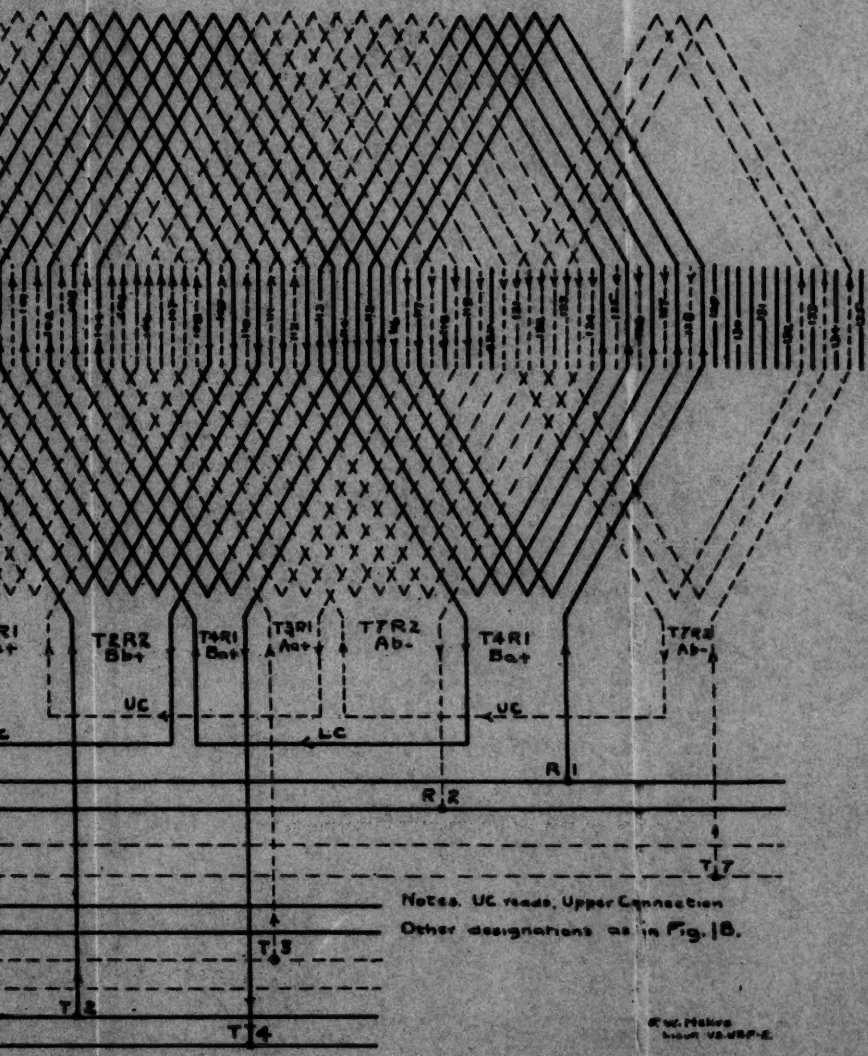


Diagram 19.
MOTOR WINDING
U.S.A. New Mexico
24 Poles
1/6 of Complete Winding
Phase A in broken lines.


T7R2 Ab-
T1R1 Aa-
T3R2 Bb-
T6R1 Ba-
T1R1 Aa-
T5R2 Ab+
T6R1 Ba-
T2R2 Bb+
T5R2 Ab+
T3R1 Aa+
UC
LC
Ring 1
Ring 2
R1
R2
T1
T7
T8
T6
T3
T5
T2
T4
T1 Aa-
T7 Ab-
T8 Bb-
T6 Ba-
T3 Aa+
T5 Ab+
T2 Bb+
T4 Ba+


T8R2 Bb-
T7R2 Ab-
T1R1 Ra-
T8R2 Bb-
T6R1 Ba-
T1R1 Aa-
T5R2 Ab+
T6R1 Ba-
T2R2 Bb+
T3R2 Ab+
T3R1 Aa+
UC
LC
Ring1
R1
R2
Ring 2
T1
T7
T8
T6
T3
T5
T2
T4
T1 Aa-
T7 Ab-
T8 Bb-
T6 Ba-
T3 Aa+
T5 Ab+
T2 Bb+
T4 Ba+



Notes. UC reads, Upper Connection
Other designations as in Fig. 18.

R.W. Hobbs
Insom Va. USA-E.

rectly to its right are assumed to lie in the same slot and where necessary to refer to an unnumbered conductor, it will be designated by adding ½ to its slot number. For instance, the upper conductor in slot 81 will be called conductor 81, the unnumbered lower conductor in the same slot will be designated as 81½.

At the bottom of diagram 18 are shown the leads from the switches marked T2, T7, etc. These tap into the feeding rings, represented by horizontal lines, from which are tapped off the respective divisions of the winding. The two rings which interconnect the divisions are also shown by horizontal lines above the feeding rings and are marked "Ring 1" and "Ring 2." In order to show the complete winding for four poles, it was necessary to show two sections of divisions 2 and 4, as considerable overlapping of sections is evident. Only the feeding rings and the conductors in the slots of phase A are shown and these are in broken lines. The direction of the current for the instant chosen in the discussion for diagram 17 is followed out as before, the direction of the arrows corresponding in the two diagrams. The coil groups are marked to show their start and end. Thus the three and the five-coil groups discussed in diagram 15 are in diagram 18 marked T2R2 to show that the section which they constitute is connected between terminal 2 and ring 2. The end connections marked L C (read "lower connection") are so designated to distinguish them from a similar set of end connections, not shown in diagram 18 but appearing in diagram 19. One set of end connections are *drawn* above the other in the diagrams and are therefore called the "upper connections" and the other set drawn lower down are called the "lower connections." The terms have no further significance except to distinguish the one set from the other in the diagram.

In order that, if desired, each section may be followed through, their complete paths are given below. In each case the path is followed in the same direction in which the instantaneous current is assumed as flowing:

T2R2 B*b* + T2– 97– 108½– 98– 109½– 99– 110½– 100– 111½– 101– 112½– L C– 99½– 88– 98½– 87– 97½– 86– R2.
T2– 33– 44½– 34– 45½– 35– 46½– 36– 47½– 37– 48½– L C– 35½– 24– 34½– 23– 33½– 22– R2.

T8R2 B*b* — R2– 65– 76½– 66– 77½– 67– 78½– 68– 79½– 69– 80½– L C– 67½– 56– 66½– 55– 65½– 54– T8.

T6R1 B*a* — T6– 96½– 85– 95½– 84– 94½– 83– 93½– 82– 92½– 81– L C– 70– 81½– 71– 82½– 72– 83½– R1.

T4R1 B*a* + R1– 128½– 117– 127½– 116– 126½– 115– 125½– 114– 124½– 113– L C– 102– 113½– 103– 114½– 104– 115½– T4.
R1– 64½– 53– 63½– 52– 62½– 51– 61½– 50– 60½– 49– L C– 38– 49½– 39– 50½– 40– 51½– T4.

Study of the arrows representing the instantaneous flow of the current will show very plainly the formation of the poles of the winding. In the five-coil group T4R1 and the three-coil group T8R2, current flows around in a counter-clockwise direction and in the two groups directly to the right, in a clockwise direction. A pole is thus formed in the center of each combination and as the direction of the current is opposite in each succeeding group the poles alternate in polarity, as they, of course, must. The centers of the poles are at slots 42, 58, 74, 90 and 106. The idea of the winding is then to form a pole by taking a five-coil group and combining it with the next three-coil group to the right. This checks up, since there are 8 divisions or 6 times 8 or 48 sections for the two phases, or 1 section per pole per phase for the 24-pole combination.

What has been said of phase B in diagrams 17 and 18 is equally true of phase A. If in diagram 17 we assume the in-

stantaneous direction of the current to be flowing down on lead 1′ and up on lead 1, we again find the same two parallel circuits from 1′ to 1 as we found for phase 2, namely, 1′, terminal 3, 3′, section 3, ring 1, around ring 1, section 1, 1′, terminal 1, *e*, to 1 and 1′, terminal 7, 7′, section 7, ring 2, section 5, 5′, terminal 5, *f*, 1.

In diagram 19 is given the complete winding. Whereas, in phase B, the three-coil group of a section was to the left of the five-coil group of the same section, in phase A it will be seen that the three-coil group lies to the right of the five-coil group of the same section. Also, that two five-coil groups, one from each phase lie together, and similarly two three-coil groups, one from each phase. The arrows representing the instantaneous direction of the current for the slot conductors for phase A are drawn near the top of the slots and for phase B near the bottom.

The complete section circuits for phase A are given below:

T3R1 A*a* + T3– 105– 116½– 106– 117½– 107– 118½– U C– 107½– 96– 106½– 95– 105½– 94– 104½– 93– 103½– 92– R1.
T3– 41– 52½– 42– 53½– 43– 54½– U C– 43½– 32– 42½– 31– 41½– 30– 40½– 29– 39½– 28– R1.

T1R1 A*a* — R1– 73– 84½– 74– 85½– 75– 86½– U C– 75½– 64– 74½– 63– 73½– 62– 72½– 61– 71½– 60– T1.

T7R2 A*b* — T7– 70½– 59– 69½– 58– 68½– 57– U C– 44– 55½– 45– 56½– 46– 57½– 47– 58½– 48– 59½– R2.
T7– 134½– 123– 133½– 122– 132½– 121– U C– 108– 119½– 109– 120½– 110– 121½– 111– 122½– 112– 123½– R2.

T5R2 A*b* + R2– 102½– 91– 101½– 90– 100½– 89– U C– 76– 87½– 77– 88½– 78– 89½– 79– 90½– 80– 91½– T5.

The centers of the poles of phase A are at slots 50, 66, 82 and 98. If phase A leads phase B, rotation is from right to left. If phase B leads phase A, the rotation is from left to right. If current flows in both phases of equal magnitude, as would be the case if phase A led phase B and phase B were at the 45 degree position, in the direction the arrows show, the centers of the poles are then at slots 46, 62, 78 and 94. In the region of these slots, from, say, 92 through 96 or five slots, the currents of the two phases are opposed, fixing the centers of the poles.

It will be noted that in diagram 17, ring 1 is common to both phases, joining together sections 6 and 4 of phase B and also sections 1 and 3 of phase A. The ring in potential, is equidistant from each end of the sections and joins points of no difference of potential, so that it does not upset the equilibrium of the current distribution. In fact, one ring might have been sufficient and the second was probably provided to afford greater current-carrying capacity.

What must be done in order to rearrange the winding for 36 poles is evident from diagram 19. If the two adjacent three-coil groups can be combined to form the winding for one pole of one phase and then the next five-coil group in either direction taken for the poles of the other phase and so on, the result will be obtained. To work this out and keep the instantaneous direction of the currents in their proper relation so as to form the poles properly, will require some reconnection of the groups as regards the phases and the instantaneous direction of their currents. A group may be handled in one of four ways. First, it may be left in the same phase and the instantaneous direction of its current left as before (B*b* +). Second, it may be left in the same phase, but the instantaneous direction of its current reversed (B*b* —). Third, it may be transferred to the other phase, but the instantaneous direction of its current left the same (B*a* +). Fourth, it may be transferred to the other phase and also have the instan-

taneous direction of its current reversed (A*b* —). The markings B*b* +, A*b* —, etc., indicate exactly where each coil is found in either pole combination and what changes are made in the instantaneous direction of its current. The rule for deriving the marking is simple. The coils which in the 24-pole combination are in phase A are marked with a capital A and the same for phase B. Thus in diagram 18 the markings for all the groups shown, start with B, as phase A is not shown. To the capital letter is added a small *a* or *b*, to show in which phase the group is found in the 36-pole combination. A group marked B*b*, is found in phase B for both pole combinations. Another marked A*b*, is included in phase A in the 24-pole combination, but for the 36-pole arrangement must be in phase B.

When, in going from one pole combination to the other, the instantaneous direction of the current is left the same, a + sign is added to the marking, but if the direction is reversed, a — sign is added. Thus the marking B*a* — indicates the section is in phase B for 24 poles, in phase A for 36 poles and in going from one combination to the other, the instantaneous direction of the current is reversed.

Let us in diagram 19, follow this out. The two three-coil groups, T4R1 and T3R1, are together taken to form a pole of phase A in the 36-pole combination. The instantaneous direction of the current is left the same in transferring, but while T3R1 was in phase A in the 24-pole combination, T4R1 was in phase B, so that the latter must be transferred to phase A in the 36-pole arrangement. Groups T4R1 and T3R1 are then marked B*a* + and A*a* +, respectively. To the left of T4R1 we have group T2R2. This in the 36-pole combination must be in phase B and the instantaneous direction of its current left the same. As it was in phase B in the 24-pole combination, it is marked B*b* +. Group T3R1, which forms the next pole of phase A, has already been considered. The two three-coil groups, T2R2 and T5R2 together must be in phase B and as the instantaneous direction of their currents is not

to be changed, they are marked B*b*+ and A*b* +, giving a second check on T2R2. Group T6R1 is, in the 36-pole combination, to appear in phase A and its current must be reversed. Accordingly it is marked B*a* —. This reasoning can be continued through the rest of the winding.

In diagram 20 are shown how the windings are arranged in accordance with the reasoning just presented. The switches are now thrown down and the currents in sections 2 and 3 are the same as in diagram 17. Two parallel circuits from lead 2′ to 2 (phase B) are again to be found. They are given below:

Lead 2′, to 2 { end 2′ (B *b* +), section 2 / *i*, 8, end 8′(B*b*—), section 8 } Ring 2 { section 5, end 5′ (A*b*+), 5 / section 7, end 7′ (A*b*—), 7, *l*, } *k*, *d*, lead 2

The two circuits from lead 1′ to 1, phase A, are,

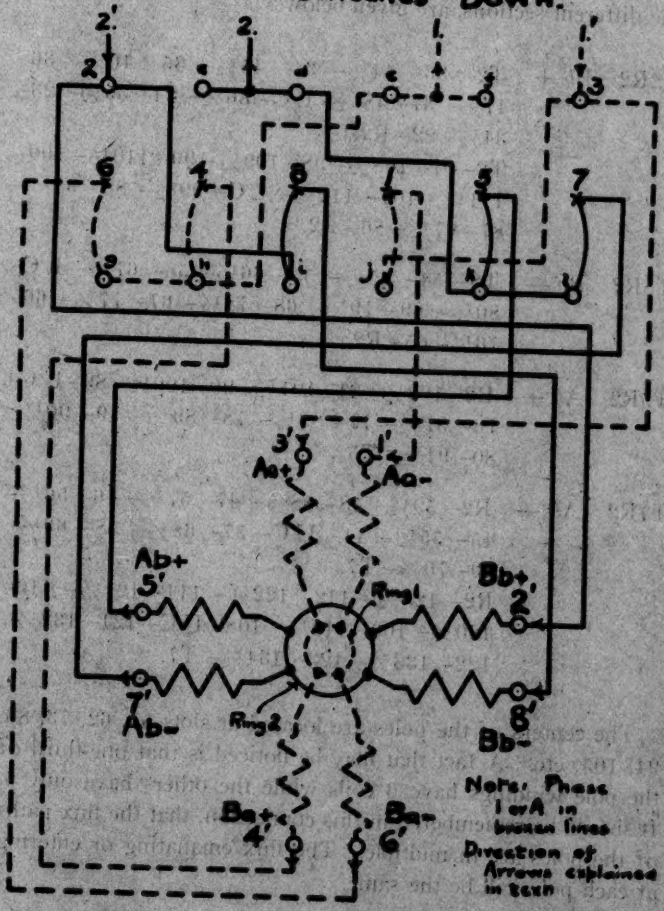
Lead 1′, 3, { end 3′ (A *a* +), section 3 / *j*, 1, end 1′ (A*a*—), section 1 } Ring 1 { section 4, end 4′ (B*a*+), 4, / section 6, end 6′ (B*a*—), 6, *g* } *h*, *e*, lead 1

All of the sections of phase A are joined by ring 1 and all of the sections of phase B, by ring 2. The two phases are thus not connected anywhere, after leaving the alternator, in the 36-pole combination. Comparing diagrams 17 and 20 will further show the use of the markings. Section 2 (B*b* +) and 3 (A*a* +) are left the same in both diagrams. Section 1 (A*a* —) and 8 (B*b* —), in going from 24 to 36 poles are left in the same phases respectively, but the instantaneous direction of their currents are changed. In diagram 17, current flows from ring to end and in diagram 20, from end to ring. Sections 5 (A*b* +) and 4 (B*a* +), are transferred, each to the other phase. The instantaneous direction of their currents is left the same. The same applies to sections 7 (A*b* —) and 6 (B*a* —), except that the instantaneous directions of their currents is reversed in going from one arrangement to the other.

Diagram 20.

MOTOR POLE CHANGING SWITCH and CONNECTIONS TO MOTORS.

36 Pole Connection Switches Down.



Authors Lieut Usher.

Turning now to diagram 21, we have the complete winding for phase B arranged for 36 poles. All that has been said from where we started to investigate what would have to be done to rearrange the winding for 36 poles, will be here found to have been followed. The complete paths for phase B, through the different sections, are given below:

T2R2 B*b* + T2– 33– 44½– 34– 45½– 35– 46½– 36– 47½– 37– 48½– L C– 36½– 24– 35½– 23– 34½– 22– R2.
T2– 97– 108½– 98– 109½– 99– 110½– 100– 111½– 101– 112½– L C– 99½– 88– 98½– 87– 97½– 86– R2.

T8R2 B*b* — T8– 54– 65½– 55– 66½– 56– 67½– L C– 80½– 69– 79½– 68– 78½– 67– 77½– 66– 76½– 65– R2.

T5R2 A*b* + R2– 102½– 91– 101½– 90– 100½– 89– U C– 76– 87½– 77– 88½– 78– 89½– 79– 90½– 80– 91½– T5.

T7R2 A*b* — R2– 59½– 48– 58½– 47– 57½– 46– 56½– 45– 55½– 44– U C– 57– 68½– 58– 69½– 59– 70½– T7.
R2– 123½– 112– 122½– 111– 121½– 110– 120½– 109– 119½– 108– U C– 121– 132½– 122– 133½– 123– 134½– T7.

The centers of the poles are located at slots 51, 62, 73, 88, 94, 105, etc. A fact that may be noticed is that one-third of the pole windings have 6 coils while the others have only 5. It should be remembered in this connection, that the flux paths of the poles are in multiple. The flux emanating or entering at each pole will be the same.

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36–
23–

100–
3½–

L C–
66–

U C–
0½–

6½–
9½–

110–
2½–

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paths
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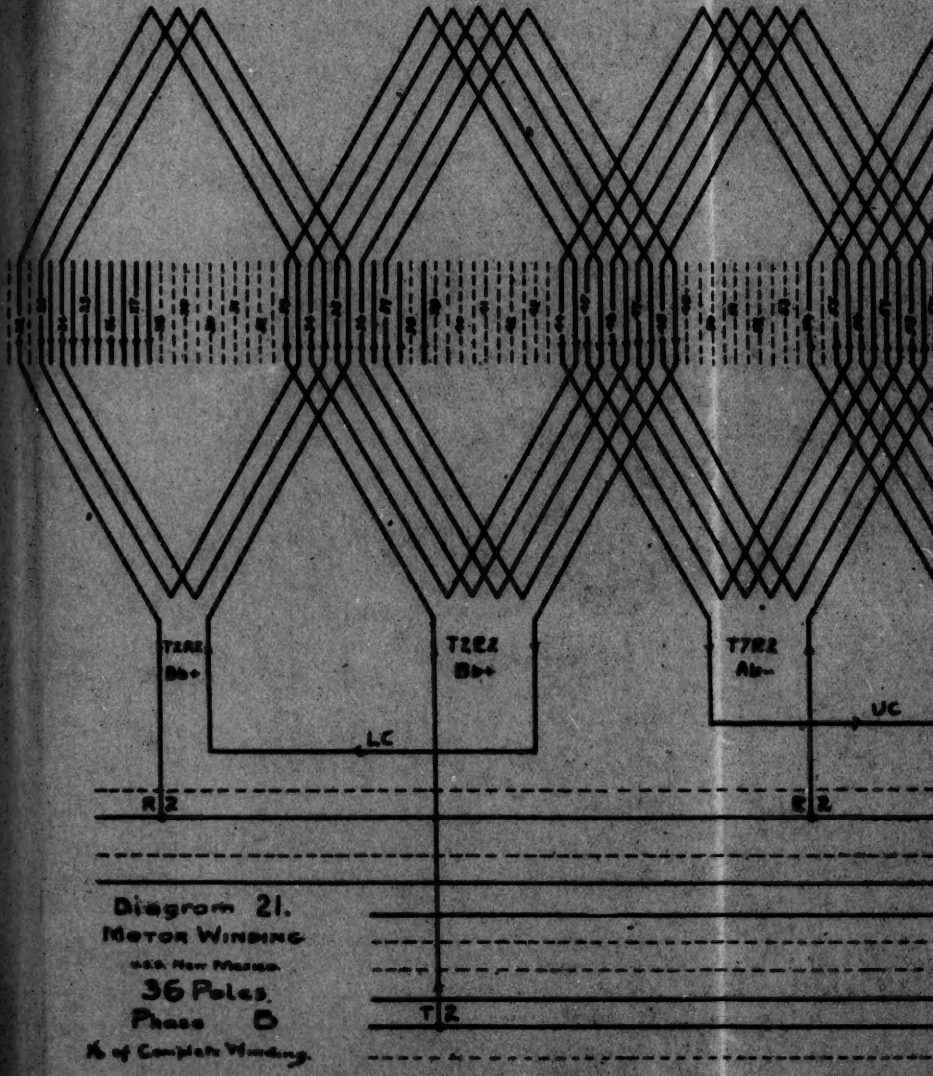
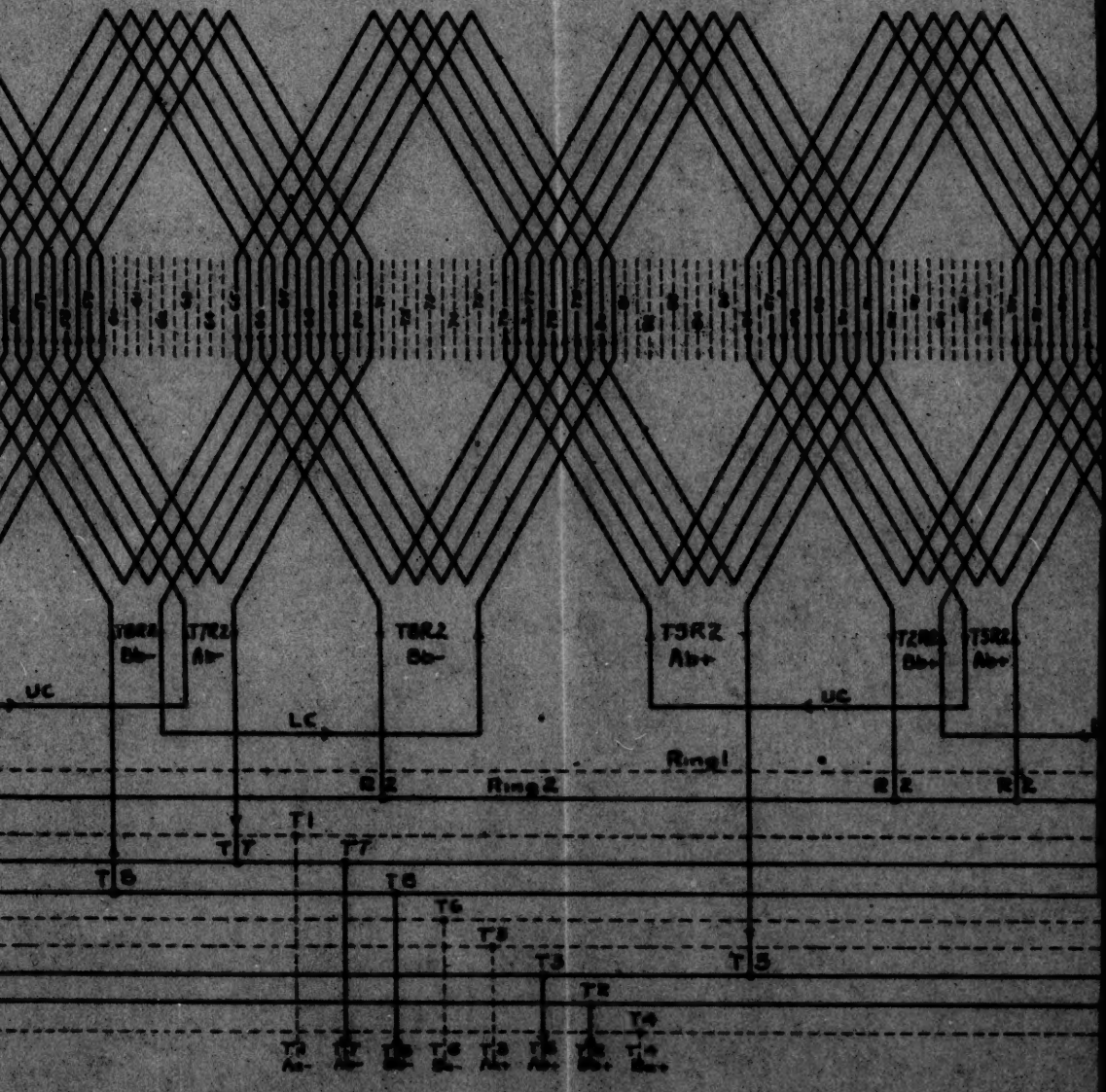
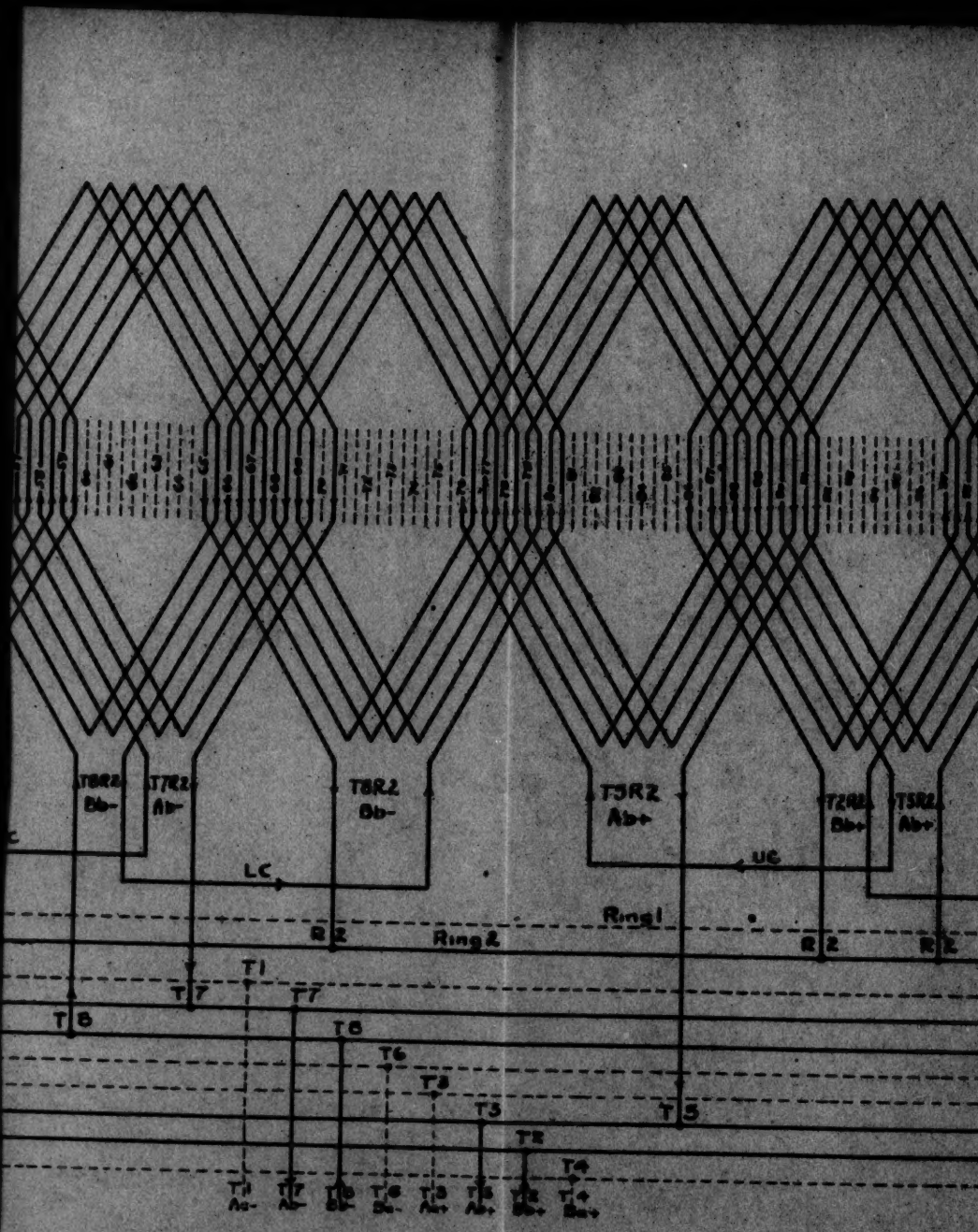
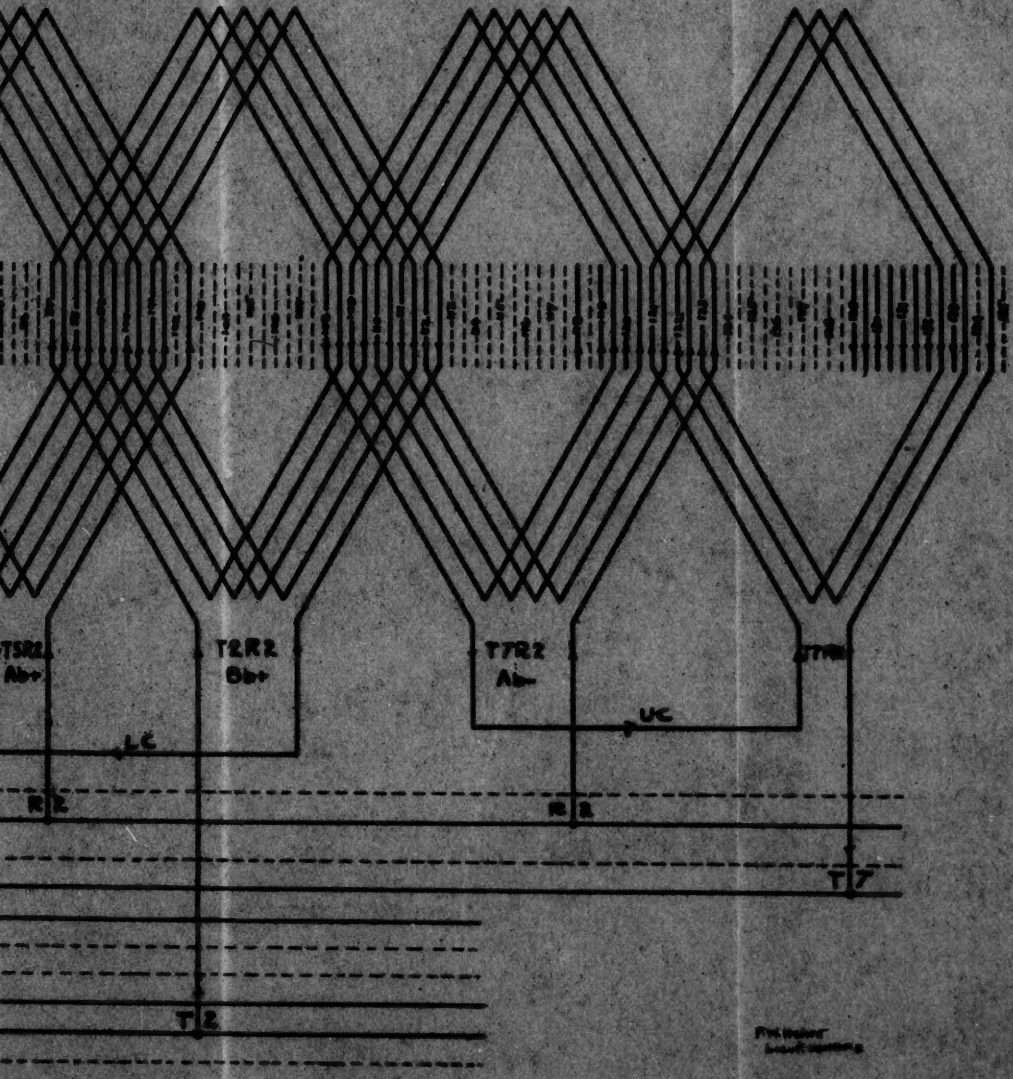


Diagram 21.
Motor Winding
U.S.A. New Mexico
36 Poles.
Phase B
¼ of Complete Winding.


T8R2 Bb-
T7R2 Ab-
T8R2 Bb-
T3R2 Ab+
T2R2 Bb+
T3R2 Ab+
UC
LC
UC
Ring1
Ring2
T1
T7
T8
T6
T5
T4
T3
T2
T9


T8R2 Bb-
T7R2 Ab-
T8R2 Bb-
T3R2 Ab+
T2R2 Bb+
T5R2 Ab+
LC
UC
Ring1
Ring2
R2
R2
R2
T1
T7
T7
T8
T8
T6
T3
T5
T2
T4
T1 Aa-
T7 Ab-
T8 Bb-
T6 Ba-
T3 Aa+
T5 Ab+
T2 Bb+
T4 Ba+


T2R2
Bb+
T7R2
Ab-
UC
LC
R 2
R 2
T 7
T 2

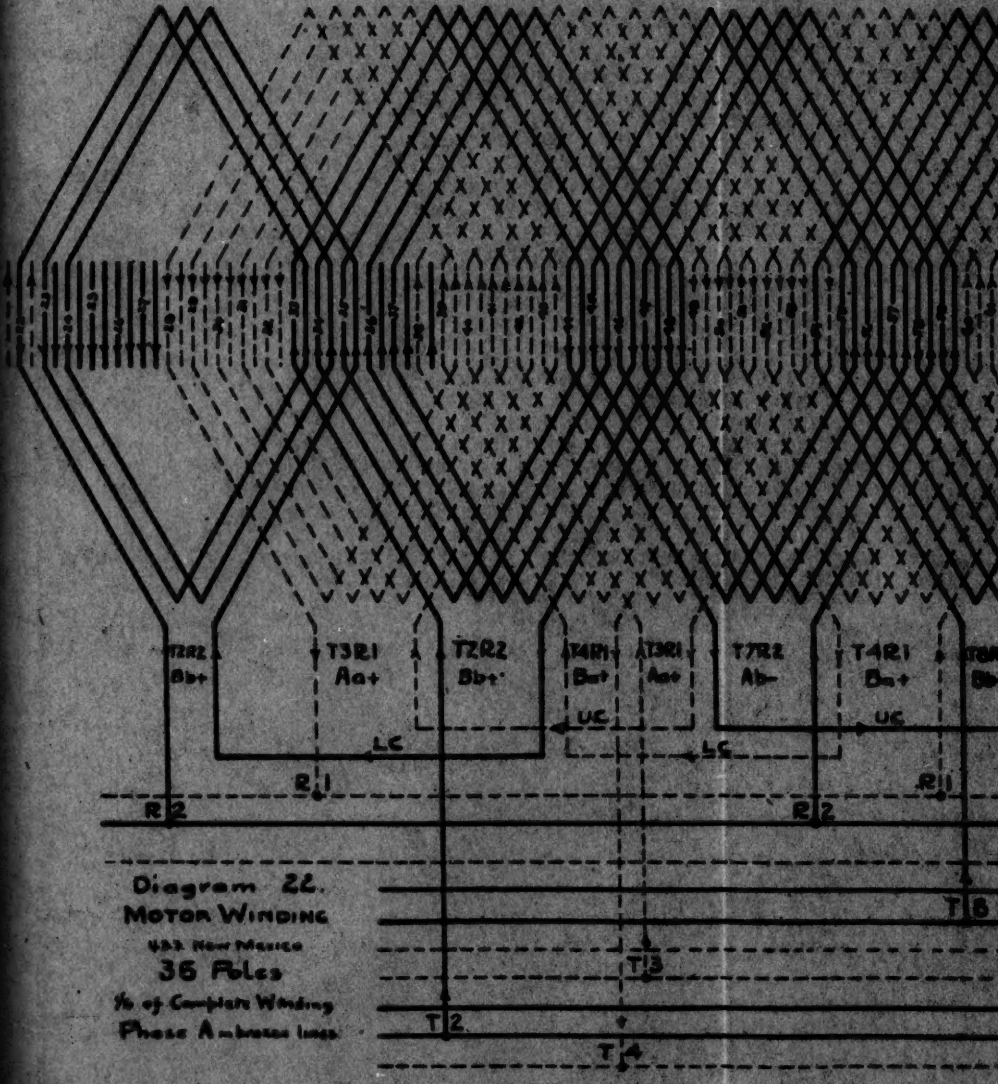
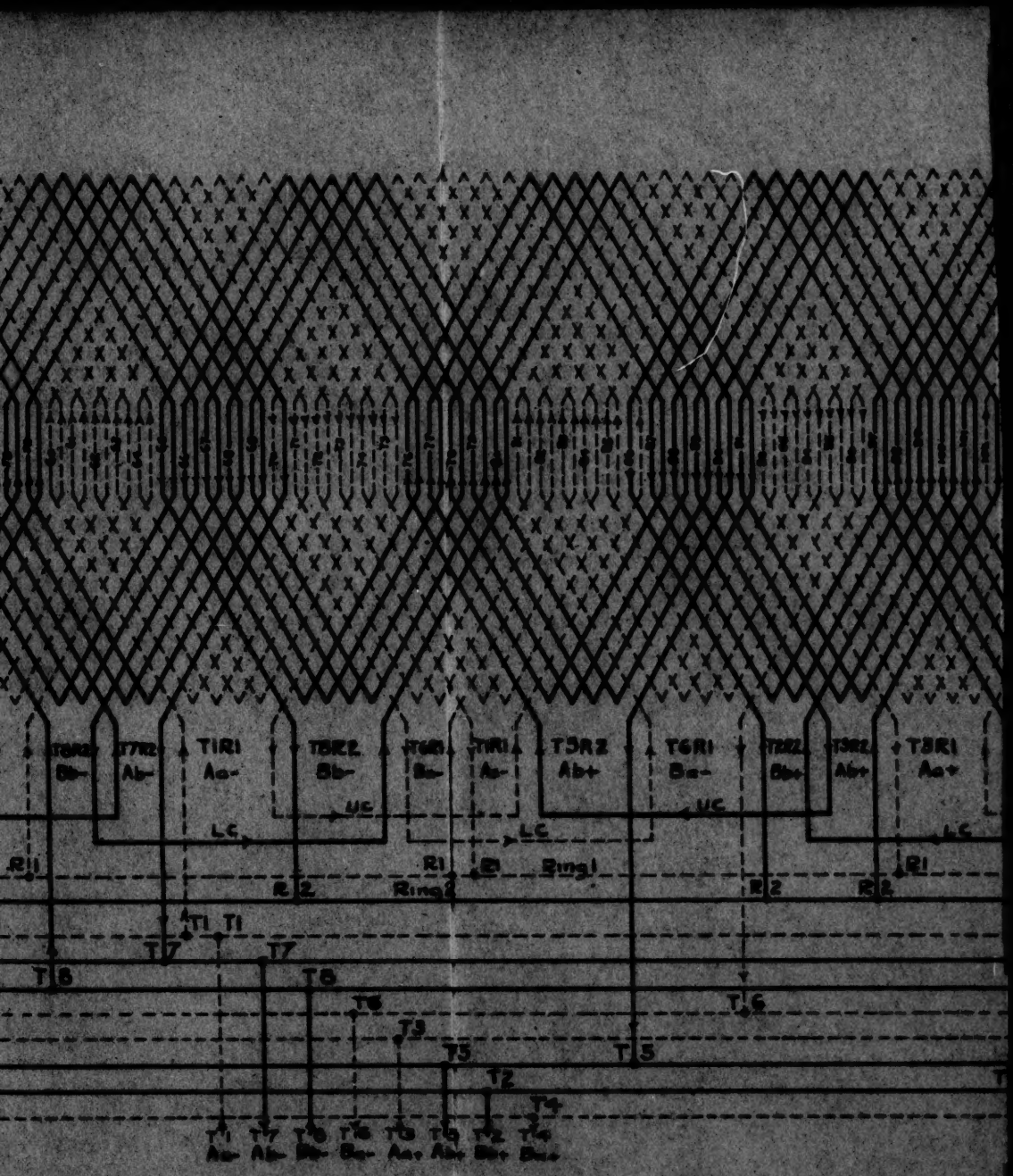
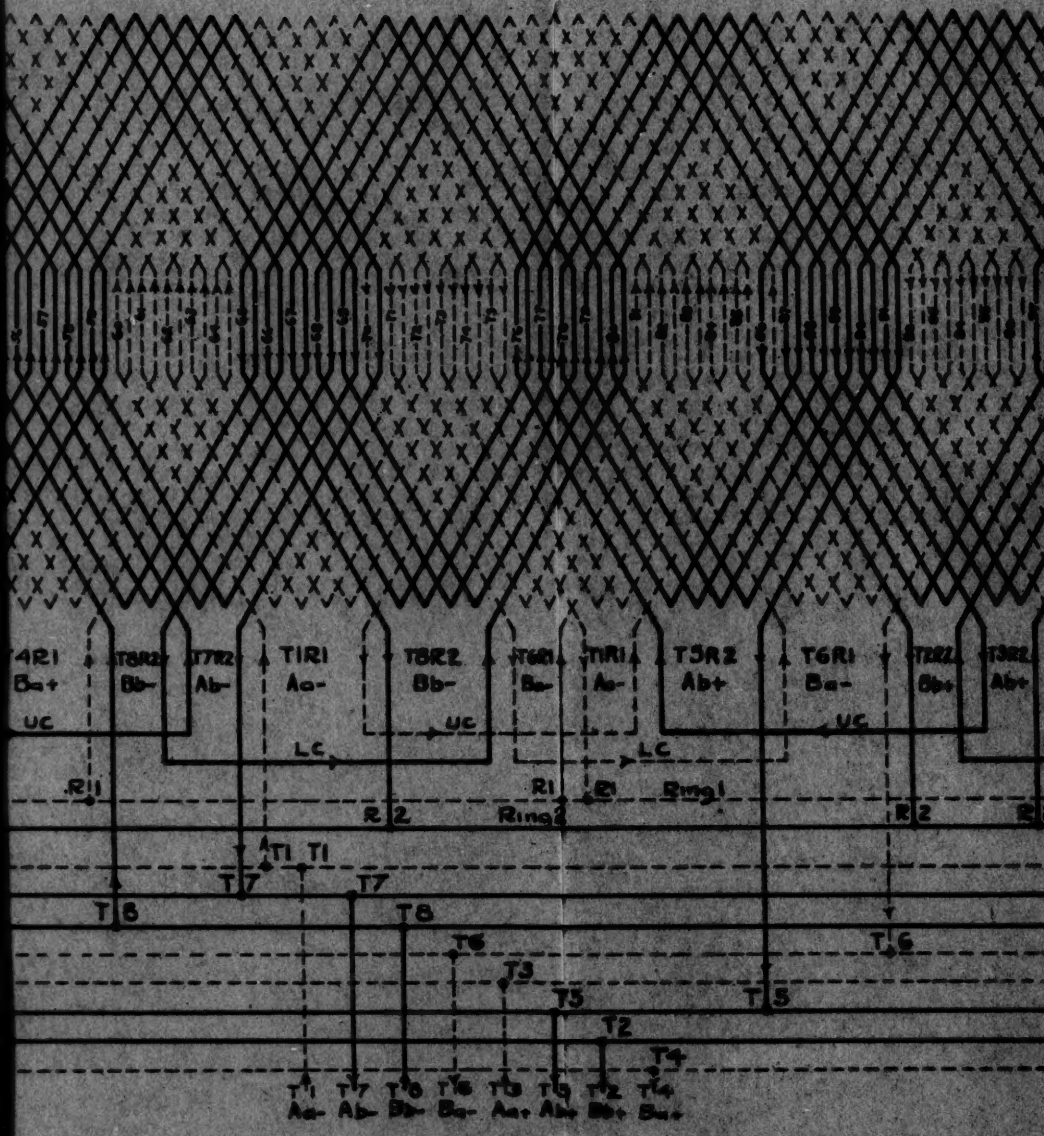
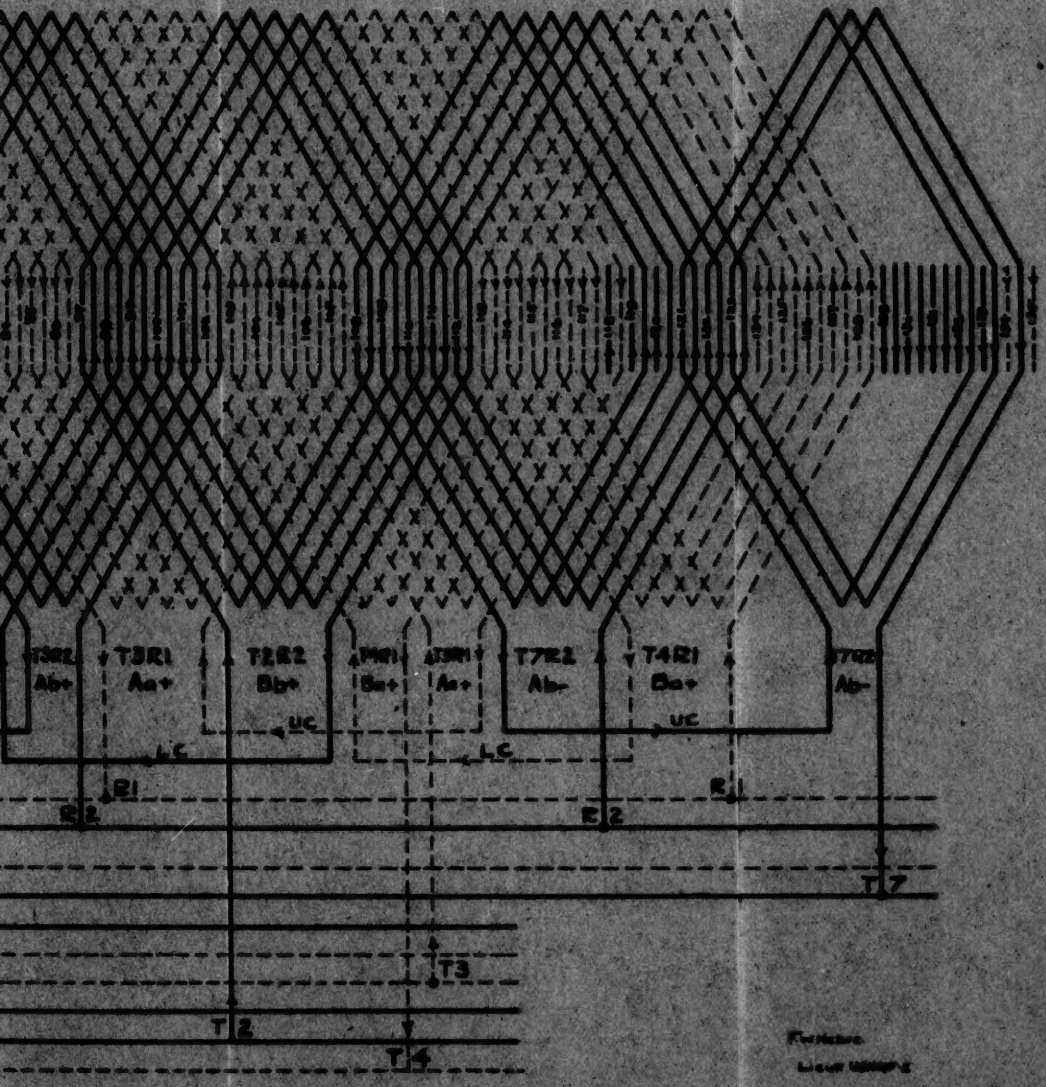


Diagram 22.
MOTOR WINDING
483 New Mexico
36 Poles
⅙ of Complete Winding
Phase A — heavy lines


T6R2 Bb-
T7R2 Ab-
T1R1 Aa-
T8R2 Bb-
T4R1 Ba-
T4R1 Aa-
T3R2 Ab+
T6R1 Ba-
T2R2 Bb+
T3R2 Ab+
T3R1 Aa+
UC
LC
R1
R2
Ring1
Ring2
T1
T7
T8
T6
T9
T5
T2
T4
T1 Aa-
T7 Ab-
T8 Bb-
T6 Ba-
T9 Aa+
T5 Ab+
T2 Bb+
T4 Ba+


T4R1
Ba+
T8R2
Bb-
T7R2
Ab-
T1R1
Aa-
T8R2
Bb-
T6R1
Ba-
T1R1
Aa-
T5R2
Ab+
T6R1
Ba-
T2R2
Bb+
T3R2
Ab+
UC
LC
R1
R2
Ring1
Ring2
T1
T7
T8
T6
T3
T5
T2
T4
T1 Aa-
T7 Ab-
T8 Bb-
T6 Ba-
T3 Aa+
T5 Ab+
T2 Bb+
T4 Ba+


T3R2
Ab+
T3R1
Aa+
T2R2
Bb+
T4R1
Ba+
T7R2
Ab-
UC
LC
R1
R2
T7
T3
T2
T4

In diagram 22 is given the complete winding arranged for 36 poles. The complete paths for phase A are as given below:

T3R1 A*a* + T3– 41– 52½– 42– 53½– 43– 54½– U C– 43½– 32– 42½– 31– 41½– 30– 40½– 29– 39½– 28– R1.
T3– 105– 116½– 106– 117½– 107– 118½– U C– 107½– 96– 106½– 95– 105½– 94– 104½– 93– 103½– 92– R1.

T1R1 A*a* — T1– 60– 71½– 61– 72½– 62– 73½– 63– 74½– 64– 75½– U C– 86½– 75– 85½– 74– 84½– 73– R1.

T4R1 B*a* + R1– 64½– 53– 63½– 52– 62½– 51– 61½– 50– 60½– 49– L C– 38– 49½– 39– 50½– 40– 51½– T4.
R1– 128½– 117– 127½– 116– 126½– 115– 125½– 114– 124½– 113– L C– 102– 113½– 103– 114½– 104– 115½– T4.

T6R1 B*a* — R1– 83½– 72– 82½– 71– 81½– 70– L C– 81– 92½– 82– 93½– 83– 94½– 84– 95½– 85– 96½– T6.

The centers of the poles produced by the currents of phase A at their maximum value and phase B at zero current, are located at slots 57, 67, 78, 89, 99, 110, etc. Should the currents be of equal magnitude in both phases and the direction of their instantaneous currents as indicated by the arrows, the centers of the poles will be slots 43 and 44, 54, 64 and 65, 75 and 76, 86, 96 and 97, 107 and 108, 118, etc. The phase currents in slots 54, 86, 118, etc., for the instant chosen are actually flowing in opposite directions, but in all other slots are in the same direction.

2B. WIRING FOR METERS, RELAYS, ETC.

a. Generator meters.
b. Motor meters.
c. Stability indicator.
d. Under-current relay.
e. Temperature indicator.
f. Balance relay.

a.—The wiring for the meters of one generator is given in diagram 23, the power cables between the generator disconnecting switch and the motor reversing switch being shown on the left. In one cable of each phase, a current transformer with a ratio of 600 to 1 is inserted to furnish the current for the ammeter and the current coils of the two phase indicating wattmeter.

A current instrument transformer has an iron core, a primary and a secondary winding, insulated from each other. The primary winding consists of one or more turns and is connected in series with the main leads, and its secondary, consisting of many turns, is connected to the meters to measure the current, etc. The use of current transformers is standard practice in alternating current installations, whenever the potential of the system is over about 500 volts. This is done to protect the operators by keeping high voltages from the instruments.

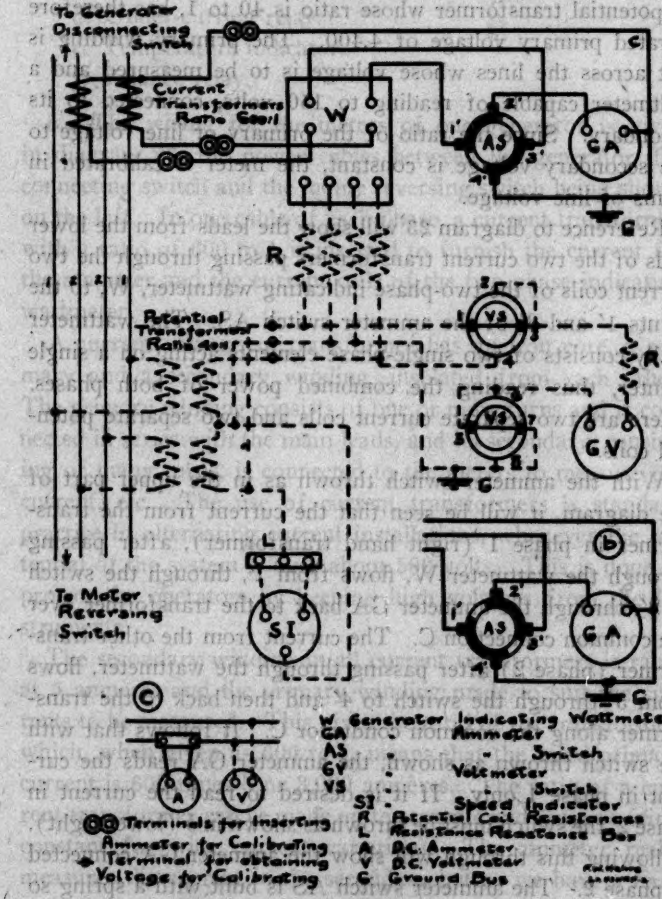
The secondary winding in all current transformers is rated at 5 ampères and the primary winding made to suit the currents to be measured. This gives the ratio of the transformer, which, when given as 600 to 1, means that the rated primary current is 600 times 5 or 3,000 ampères. The ratio of a current transformer can be made quite accurate and remains fairly constant for wide current variations. The ammeter really measures the current in the secondary but as we have a fixed ratio between the line or primary current and the secondary current, the meter is calibrated directly in terms of the line current.

A potential transformer also has an iron core, a primary and a secondary winding, all insulated from each other. The number of turns in the two windings are in proportion to the voltages involved, the customary secondary voltage being 110. A potential transformer whose ratio is 40 to 1, has therefore a rated primary voltage of 4,400. The primary winding is put across the lines whose voltage is to be measured and a voltmeter capable of reading to 150 volts, connected to its secondary. Since the ratio of the primary or line voltage to the secondary voltage is constant, the meter is calibrated in terms of line voltage.

Reference to diagram 23 will show the leads from the lower ends of the two current transformers passing through the two current coils of the two-phase indicating wattmeter, W, to the points 1′ and 3′ of the ammeter switch AS. The wattmeter really consists of two single-phase elements acting on a single pointer, thus reading the combined power of both phases. There are two separate current coils and two separate potential coils.

With the ammeter switch thrown as in the upper part of the diagram, it will be seen that the current from the transformer in phase 1 (right hand transformer), after passing through the wattmeter W, flows from 1′, through the switch to 2′, through the ammeter GA back to the transformer over the common connection C. The current from the other transformer (phase 2) after passing through the wattmeter, flows from 3′ through the switch to 4′ and then back to the transformer along the common conductor C. It follows that with the switch thrown as shown, the ammeter GA reads the current in phase 1 only. If it is desired to read the current in phase 2, the switch must be thrown as shown in *b* (lower right). Following this through will show the ammeter GA connected in phase 2. The ammeter switch AS is built with a spring so that it will not remain in any position but what will make contact so as to put the ammeter into either phase 1 or 2. In other words, the switch cannot be left with either or both

Diagram 29.
Generator Meters



secondary circuits open. This is done so that the wattmeter will always read the total generator power and therefore not mislead the officer on watch and also not leave the current transformers with their secondaries open circuited. The latter condition is apt to be dangerous.

A connection is also made from the common conductor to the "ground bus" G, which is a separate bus on the back of the main board and which is in turn connected to the metal of the ship. This prevents any high voltage from building up between the metal parts of the ship (ground) and the meter covers, etc. The terminals shown in the lines from the transformers, are for the purpose of inserting portable ammeters, etc., for calibration or measurement of the currents flowing.

Two potential transformers are connected with their primaries across each phase. The secondaries are tied together, the common connection being also connected to the ground bus G. The three leads are carried to the wattmeter, where they are connected to the proper potential coils through external resistances R. The three potential leads are next carried to the voltmeter switch VS, which is in two parts, operated, however, together by a single handle. In the diagram the two blocks of each part, joined together horizontally, are shown making contact across terminals 1 and 3, and 5 and 7. If the switch is thrown, contact is made from terminal 2 to 4 and from terminal 6 to 8.

Study of the switch will show that the lower portion only opens the common lead from the transformers and the upper portion selects which transformer the voltmeter is to be connected across. As shown, the switch has connected the voltmeter across the transformer in phase 2. If the voltage of phase 1 were desired, the switch would be thrown to make contact across terminals 2 and 4 and across 6 and 8. It will be noted that the switch breaks the circuit to the voltmeter in four places. This switch may be left open without any danger. Terminals for connecting portable voltmeters for calibration purposes are also shown in the leads from the trans-

formers. All such calibration terminals are conveniently located on a testing board placed behind the main switchboard.

A speed indicator, S. I., is also shown. This is what is usually called a frequency meter, which as its name implies is used to indicate the frequency of the supply voltage. As the frequency of any power supply is fixed by the speed of the alternator, the frequency meter may be calibrated in terms of the alternator speed. Additional scales were also added to the meters installed, to indicate motor speeds, for both 24 and 36 pole combinations.

The instrument, as will be seen in diagram 23, is connected as a voltmeter across phase 2 and briefly its current enters a resistance reactance box I. Here it divides, part passing through a non-inductive resistance (in the box) to one meter terminal, through one of the two coils of the instrument to a common point and back to the potential transformer. The other part of the current passes through an inductance (in the box), through the second coil of the meter and then unites with the first part of the current. The strength of the current through the non-inductive resistance is independent of frequency, but that through the inductance, varying inversely with the frequency, causes the pointer to change its position as the frequency is varied. It has, however, no springs to its moving element and its pointer simply floats. When voltage is applied it moves to the proper indication, but when voltage is removed its reading means nothing. If either alternator is disconnected at its disconnecting switch, all the generator meters for that machine are dead and naturally, not having any voltage, the indication of the speed indicator is not only meaningless but proves misleading in a moment of haste. It frequently occurs that one alternator is turning over at low speed as a standby and it is essential, since the alternators are in separate compartments, that the officer of the watch know its speed while idling. It proved necessary to have some positive means of indicating their speeds, whether the alternators were connected or not. Subsequent to the original installa-

tion, magnetos were connected to the alternators, which operate voltmeters, calibrated to speed, on the main boards. The voltage of a magneto (which has permanent magnets for poles) varies directly with speed, giving a uniform scale on the indicating instruments. These have proven quite satisfactory.

In part *c* of diagram 23 is shown the customary method of connecting D.C. ammeters and voltmeters, using external shunts for the former.

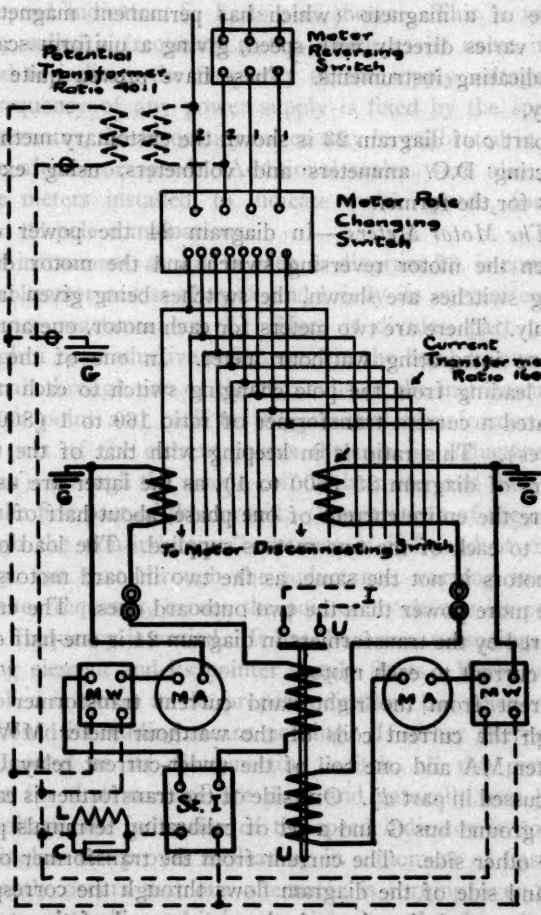
b. The Motor Meters.—In diagram 24 the power cables between the motor reversing switch and the motor disconnecting switches are shown, the switches being given in outline only. There are two meters for each motor, one ammeter and one integrating watthour meter. In one of the eight cables leading from the pole changing switch to each motor, is located a current transformer of ratio 160 to 1 (800 to 5 ampères). This ratio is in keeping with that of the transformers of diagram 23 (600 to 1), as the latter are used to measure the entire current of one phase, about half of which passes to each of the two motors supplied. The load on the two motors is not the same, as the two inboard motors take a little more power than the two outboard ones. The current measured by the transformers in diagram 24 is one-half of the phase current to each motor.

Current from the right hand current transformer flows through the current coils of the watthour meter MW, the ammeter MA and one coil of the under-current relay U (to be discussed in part *d*). One side of the transformer is carried to the ground bus G and a set of calibrating terminals put in on the other side. The current from the transformer on the left hand side of the diagram flows through the corresponding devices and also through the current coil of the stability indicator St. I (to be discussed in part *c*).

Potential for the two watthour meters is obtained from a single potential transformer, connected across phase 2 and

Diagram 24.

Motor Meters, Stability Indicator and Under Current Relay.



G Ground Bus
MA Motor Ammeter
MW Integrating Watthour Meter
U Under current Relay
L & C Reactance in series with potential coils of St. I
Current Calibrating Terminals
Potential
I Leads to electrical locks on Reversing and Pole Changing Switches.
St. I Stability Indicator.

placed between the motor reversing and pole changing switches. The potential coils of the two watthour meters are connected in parallel across its secondary.

c. *The Stability Indicator.*—In the introduction to this article, reference was made to the fact that the voltage impressed on the motors had to be adjusted so as to make the motors operate at a good power factor. The characteristics of induction motors are such that for a given voltage and frequency, as the torque of the load is increased, a condition is reached when the torque exerted by the motors no longer increases and the motors "pull out," "stall" or "fall out of step." In other words, if the work that the motors are doing is continually increasing, a point is reached when the turning effort of the motors does not increase any further. The motors not being equal to their work, simply slow down and their speed falls to a low value, at the same time drawing a very heavy current from their supply.

It is also a characteristic of the induction motor that the maximum torque which it can develop (which is of course the pull out point) varies as the square of the voltage impressed on it. That is, if the voltage impressed on a motor is doubled, the maximum torque that it can exert without falling out of step will be increased four times. It would then appear to be advisable to operate with a high voltage at all times, were it not for another consideration.

For a given load, at a constant frequency, on an induction motor, it is found that the power factor at which the motor operates varies considerably with voltage variation. Power factor may be defined in two ways. We may call it a number, equal to or less than one, by which the product of volts and ampères must be multiplied, to get the actual power in watts. As the watts can never be greater than the product of volts and ampères, the number may also be expressed in per cent, the maximum possible value then being 100 per cent. Or we may define power factor as the cosine of the angle between the voltage and the current.

To illustrate from the first definition, suppose a motor is operating at 0.8 power factor, taking 150 ampères at 1,000 volts. The power taken by the motor is then $1,000 \times 150 \times 0.8 = 120,000$ watts, or 120 kilowatts. Another motor taking the same power at a power factor of 0.6 and 1,000 volts would require

$$\frac{120,000}{1,000 \times 0.6} = 200 \text{ ampères.}$$

From this it follows that for a given amount of power at a certain voltage, the lower the power factor, the greater the current.

It would be found, if we impressed a voltage much higher than what it was designed for, on a commercial induction motor, operating at a constant load and frequency, that its power factor would be very low, probably below 0.5. If we were now to gradually lower the voltage, the current taken would decrease and its power factor would increase. This, as we continued to decrease the voltage, would go on until a maximum power factor would be reached and on further decrease of voltage the current would start to increase and the power factor to decrease. We would, however, be able to decrease the voltage only a little beyond the value that gave maximum power factor, before the motor would stall. In other words, an induction motor, operating with a fixed load at the maximum power factor it is capable of, by voltage adjustment, is very near its pull out point.

Consideration then of motor operation from the standpoint of power factor would indicate the advisability of running at maximum power factor. The amount of heat produced by the current in the motor and generator windings varies as the square of the current, double current giving four times the heating, etc. The lower the power factor of the motors, therefore, the greater the amount of heating developed in the motors and alternators. This in itself lowers economy and besides, the blowers, circulating air through the machines must

be speeded up as the amount of heating in the machines increases. At high loads the matter of heating becomes an operating problem, requiring careful attention to ventilation to prevent excessive rise of temperature in the windings.

Evidently a compromise must be made between the limits of high voltage, giving high pull out point and low power factor on one hand and low voltage, giving a low pull out point and high power factor on the other. Incidentally the higher the voltage, the greater the excitation necessary in the generators and hence the greater the amount of heat produced in the fields of the generators and the armatures of the exciters.

Considering conditions on the *New Mexico*, it is advisable that operation be efficient from the standpoint of fuel economy. At the same time, if the ship were in column, the possibility of the motors dropping out would be a serious matter. In order, then, that the officer of the watch may tell at a glance that he has the proper voltage on the motors, the stability indicator was installed.

The meter consists really of two separate instruments, an ammeter and a voltmeter with the moving element of each acting on a single vertical shaft to which a single pointer is attached. The two parts of the instrument are so connected that the ammeter element tends to move the pointer to the right and the voltmeter element to the left. In general if the needle is on the left hand side of the scale the voltage is high, but if it moves to the right the current is becoming relatively larger, indicating that the pull out point is being approached. The scale is calibrated in even divisions from zero to ten and the danger mark is about four on the scale. The meter is, however, not a very close indicator of power factor, for if the pointer is well over to the left, the power factor may be unnecessarily poor.

The parallel combination of capacity and inductance placed in series with the potential coil, makes the proper correction on the reading of the instrument to take care of changes in frequency.

d. The Under-Current Relay.—It has been stated that no switches involving the alternating current to the motors were thrown unless the generator field circuits were opened. There is, however, a small time lag between the instant the field of the generator is opened and the time that the alternating current, flowing from the generators to the motors, dies out. In reversing, if the officer of the watch were to operate the reversing or pole changing switches (backing is done only on 36 poles), immediately on opening the field switches, he would be rupturing large currents across the former. To allow these switches to be operated only when the current has dropped to a value which they can safely handle, the under-current relay has been added.

It consists of two exciting coils, placed, as can be seen in diagram 24, in the ammeter circuits of the two motors, both coils energizing a single plunger together. The plunger in lifting, bridges two contacts which close a secondary circuit. This secondary circuit, which will be taken up in detail in part 3, closes a set of interlocks on the motor reversing and pole changing switches, so that these cannot be operated until the plunger of the delay has dropped. A blue lamp lights up when the relay closes to indicate its operation to the officer of the watch. The relay closes as soon as current is put on to start up the motors and is adjusted so as to open when the current in the secondaries of both current transformers has dropped to 0.75 ampères. Since the ratio of the current transformers is 160 to 1, this means that the current to each motor must fall to 120 ampères before the relay opens. The reversing and pole changing switches can thus be opened when 240 ampères are flowing through them. Should one of the motors on a side be disconnected at its disconnecting switch, one of the relay coils will be dead and the relay will open when the current in the secondary of the current transformer of the live motor has dropped to 1.5 ampères, or the actual current, through the reversing and pole changing switches to 240 ampères, the same as when both motors are in operation.

In operation, as soon as the signal to back has been received from the bridge, the officer of the watch slows down the turbines by rapidly moving up the speed control levers and then rapidly pushes up the field levers, opening the generator fields. He then waits for the current to die down to the safe limit, this fact being indicated by the blue lights of the under-current relay going out. As soon as this happens he operates the reversing and pole changing levers as necessary.

The delay occasioned by the under-current relay is not a serious one as it has been found that backing the ship can be done in about 20 seconds from the time the signal is received until the motors start to go astern. About 8 seconds of this time is consumed in the operation of the under-current relay.

In case of great necessity an emergency pull button, mounted on the casing of the under-current relay, may be used to open the relay contacts and so release the interlocks on the reversing and pole changing switches without waiting for the relay to function.

e. Temperature Indicator.—In the operation of electrical machinery it is very important that the temperatures of the different parts of the machines do not exceed certain safe limits. Some of these parts, like the bearings, are accessible, but to obtain the temperature of the windings which are imbedded in the iron core is more difficult. Accordingly when the generators were built, copper resistors were placed in the slots of the stators in close contact with the insulation of the winding. The temperature of a resistor becomes the same as that of the winding where it is placed and it is the temperature of the resistor that we determine by the variation of its resistance.

In diagram 25 is shown a simple form of the temperature indicator and its circuits. The instrument is a galvanometer having permanent magnets, the same as d.c. meters. Its moving element consists of two separate coils, connected differentially, that is, the lower coil in diagram 25 causes the needle to move to the right while the upper coil tends to throw it

to the left. Excitation is obtained from the operating bus on the main switchboard and we pass from the positive bus to terminal 1 of the meter. The current here divides, part flowing through the upper coil, out at terminal 2, along lead A, through the resistor or temperature coil imbedded in the gen-

Diagram 25
Temperature Indicator.

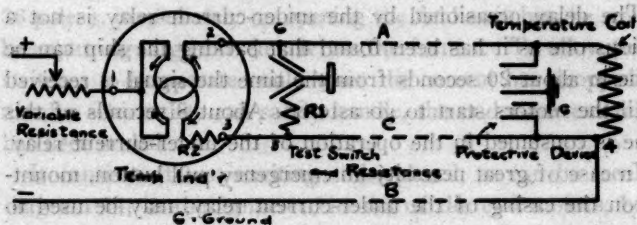
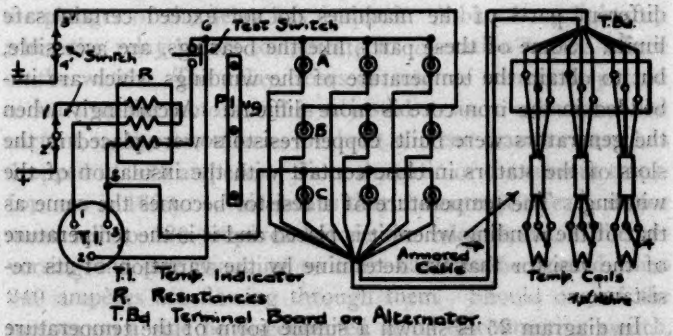


Diagram 26
Temperature Indicator Circuits



erator to the point 4 and back to the neutral of the operating bus along lead B. The other portion of the current passes through the lower coil of the meter, through a small resistance R2 (whose resistance is independent of temperature), out at terminal 3, along lead C, to terminal 4 and back along lead B.

The operation of the instrument can readily be understood. The strength of the current in the lower coil, R2, and lead C is independent of the temperature, while the current in the other path (along lead A) depends on the resistance of the temperature coil in the machine. If the temperature of the latter rises, its resistance also increases and the current along path A decreases. The current in path C remaining the same, the lower exerts a relatively greater torque than the upper coil and the needle moves to the right, indicating a higher temperature. For some value of temperature of the temperature coil and therefore of its resistance, the current in path A will equal that in path C and there will be no net torque exerted on the pointer of the instrument by the two differential coils. Springs are adjusted to the moving element making the needle come to rest at this temperature on the scale when all voltage is taken off the system.

The self-opening, pull button test switch and resistance R1 are connected across lines A and C in parallel with the temperature coil. If the test switch is closed, additional current will flow through the upper coil to point 6, through the switch and R1 to point 5 and then back via point 4 along lead B. Thus closing the switch causes the current flowing through the upper coil to be increased by whatever flows through R1 and the needle will move to the left, if the system is in working order.

The protective device shown, consists of a number of disks of insulating material supported by spring clips and placed across the temperature coils at the terminal board of the generator. Between each set of disks there is a connection made to the ground (frame of the machine in this case). Should there be any excessive voltage impressed on the temperature indicator circuit due to breaking down of the insulation of the machine windings, this high voltage will puncture the insulating disks and discharge to ground, thus protecting the operators. (The variable resistance shown to the left of the temperature indicator is for the purpose of adjusting the in-

strument for the voltage on which it is to be used. Once adjusted it should not require any change.)

In diagram 26 is given the complete wiring of the temperature indicator system as installed, corresponding points of diagram 25 being similarly marked. As there are three sets of temperature coils imbedded in the generator armature, the same instrument is made to serve all of them through the use of a portable plug switch. The plug has three rods which, when inserted into a vertical row of jacks, makes a connection across the two sleeves of each jack, indicated diagrammatically by the two concentric circles.

It will be seen that the negative lead B is carried all the way through, to the temperature coil, to which it is connected at the point 4. It might be suggested that it could be tapped in at point 5, dispensing with one-third of the jacks, etc. Were this done, inaccuracies, caused by change in resistance of the leads A and C, due to temperature variations, would enter. With all three leads carried through, this will not happen, as all three are at the same temperature.

The protective device of diagram 25 is not shown in diagram 26. The voltage switch in diagram 26 is for the purpose of removing potential from the system when not in use.

On the *New Mexico*, temperature coils were built into the generators only. In later installations they will be put into the motors as well.

f. The Balance Relay.—To afford protection against short circuits and grounds in the generator windings or the cables, a balance relay is placed in each generator circuit. Its mechanical construction is outlined in diagram 28 and its electrical circuits are shown in diagram 27. It consists of six units, electrically separate, but mechanically interconnected. Each unit consists of a plunger which moves vertically, a coil and a dashpot, the coil when energized tending to pull the plunger down. Each plunger when down, closes a set of contacts which in turn open the main field switches. This feature will be taken up in 3B.

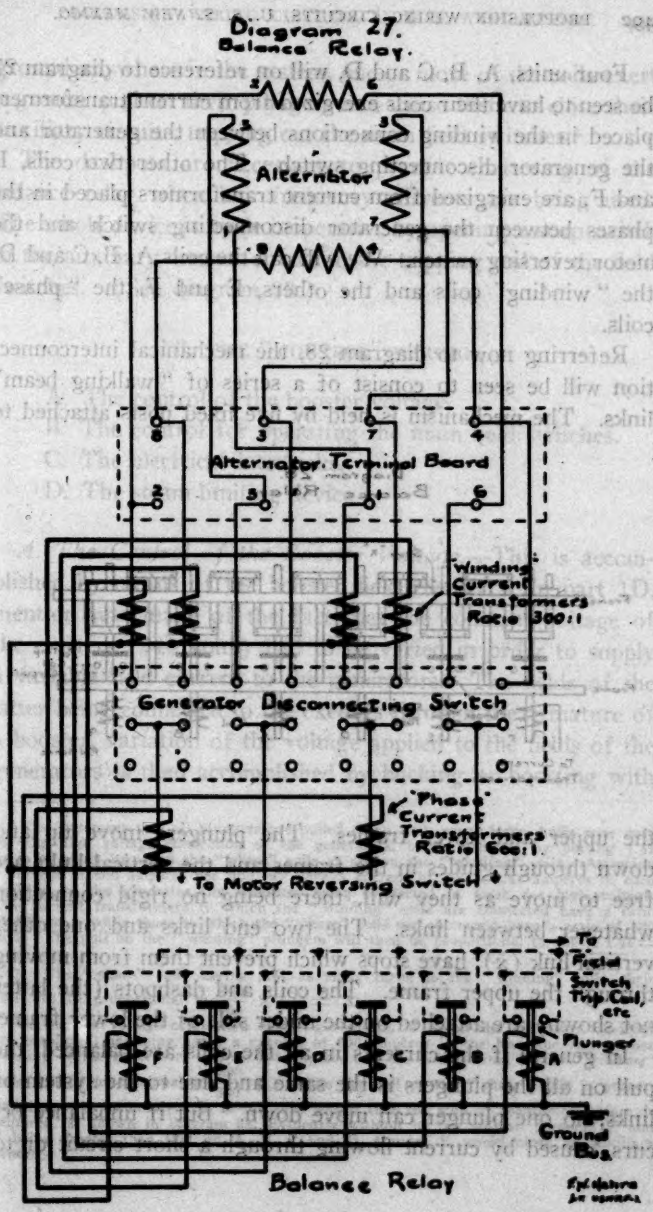
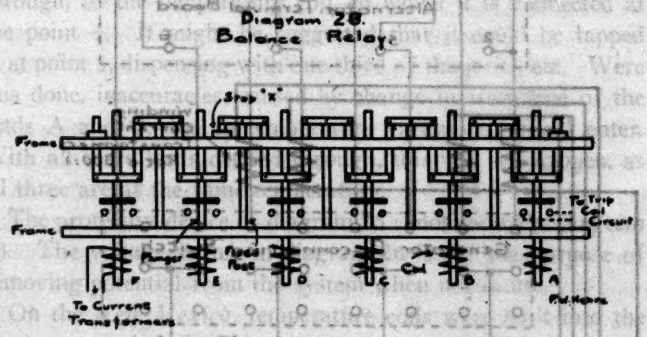


Diagram 27.
Balance Relay.
Alternator
Alternator Terminal Board
Winding
Current
Transformers
Ratio 300:1
Generator Disconnecting Switch
Phase
Current
Transformers
Ratio 600:1
To Motor Reversing Switch
To
Field
Switch
Trip Coil,
etc.
Plunger
Ground
Bus
Balance Relay

Four units, A, B, C and D, will on reference to diagram 27 be seen to have their coils energized from current transformers placed in the winding connections between the generator and the generator disconnecting switch. The other two coils, E and F, are energized from current transformers placed in the phases between the generator disconnecting switch and the motor reversing switch. We will call the coils A, B, C and D, the "winding" coils and the others, E and F, the "phase" coils.

Referring now to diagram 28, the mechanical interconnection will be seen to consist of a series of "walking beam" links. The mechanism is held by five fixed posts attached to



the upper and lower frames. The plungers move up and down through guides in the frames and the vertical links are free to move as they will, there being no rigid connection whatever between links. The two end links and one other vertical link (x), have stops which prevent them from moving through the upper frame. The coils and dashpots (the latter not shown) are attached on the under side of the lower frame.

In general if the currents in all the coils are balanced, the pull on all the plungers is the same and due to the system of links, no one plunger can move down. But if unbalance occurs, caused by current flowing through a short circuit or to

ground anywhere in the system, one or more of the coils exert a greater pull on their plungers and cause them to close their auxiliary circuits, tripping out the main field switches.*

The dashpots are necessary to prevent chattering of the balance relay when low frequency currents are being used. The whole device is made inoperative by opening a snap switch in the auxiliary contact circuit to the tripping coil of the field switches. (See diagram 33.)

3. THE "CONTROL" WIRING.

A. The control of the booster voltage.
B. The control for operating the main field switches.
C. The electrical interlocks.
D. The steam limiting device.

A. The Control of the Booster Voltage.—This is accomplished by means of the booster field rheostat. In part 1D, mention was made of the fact that the constant voltage of the exciters (240 volts) had to be varied in order to supply a variable field current to the generators. The fields of the latter being connected to the exciters through the armature of a booster, variation of the voltage applied to the fields of the generators is then accomplished by bucking or boosting with

* The statement that all plungers are pulled down with equal force, holds true only for the high voltage connection of the generators, being made so by putting 1.41 times as many turns on the "phase" coils as are on the "winding" coils. Assuming a current of 600 ampères per line, we have a current of 300×1.41 ampères in each winding of the generator, its windings being connected in mesh for high voltage. The current transformers to which the "winding" coils are connected have a ratio of 300 to 1, while those to which the "phase" coils are connected have a ratio of 600 to 1. The pull on the "winding" plungers will then be proportional to $\frac{300 \times 1.41}{300} = 1.41$. The "phase" coils having 1.41 as many turns as the "winding" coils, their pull will be proportional to $\frac{600}{600} \times 1.41 = 1.41$.

For the low voltage connection of the generators, in which the generator windings are paralleled, assuming again a current of 600 ampères in the line, the current per winding of the generators will be 300 ampères and the pull exerted by the "winding" coils will be proportional to $\frac{300}{300} = 1$, while the pull of the "phase" coils is proportional to 1.41 as before. It is for this reason that the stop s, mentioned before is required, as shown in diagram 98. Evidently without it, the pull on plungers E and F being greater than that on A, B, C and D, plunger E would close its auxiliary contacts.

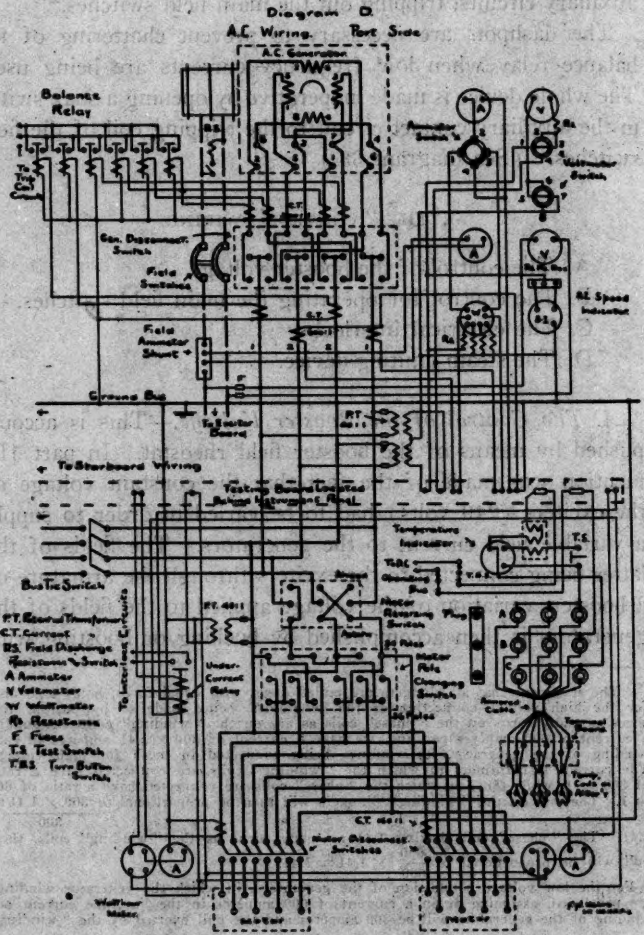


Diagram D.
A.C. Wiring. Port Side
A.C. Generator
Balance Relay
Ammeter Switch
Voltmeter Switch
Gen. Disconnect Switch
Field Switches
Field Ammeter Shunt
Ground Bus
To Starboard Wiring
Bus Tie Switch
Temperature Indicator
Motor Reversing Switches
Motor Pole Changing Switches
Under-Current Relay
Motor Disconnect Switches
Motor
Motor

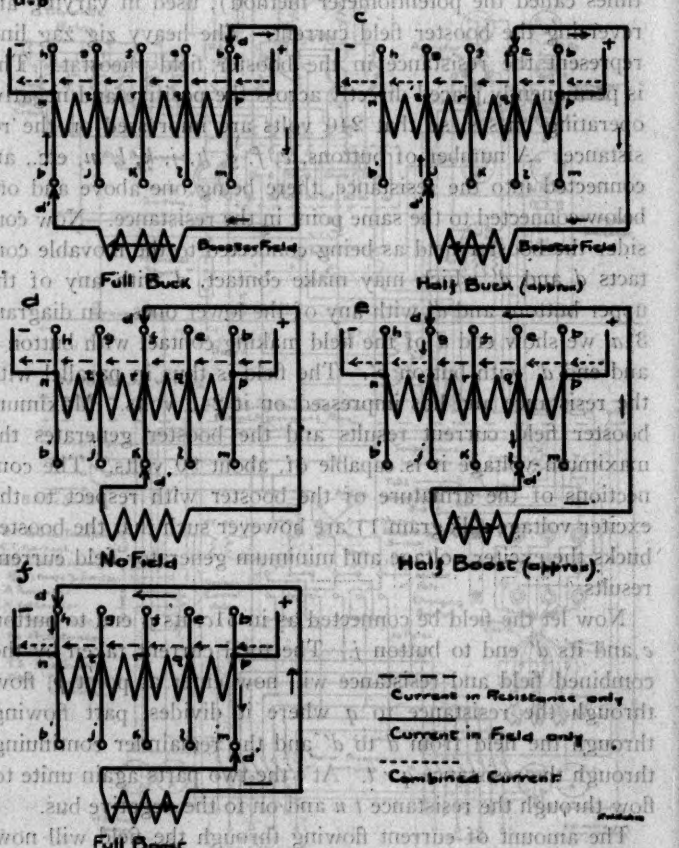
the booster. In diagram 1 was given the circuits of the generator fields and in diagram 3 the operation of the boosters was shown.

In diagram 31 is given in simple form the method (sometimes called the potentiometer method), used in varying and reversing the booster field current. The heavy zig zag lines represent the resistance in the booster field rheostat. This is permanently placed directly across the positive and negative operating busses, so that 240 volts are impressed on the resistance. A number of buttons, *e, f, g, h, j, k, l, m,* etc., are connected into the resistance, there being one above and one below connected to the same point in the resistance. Now consider the booster field as being connected to the movable contacts *d* and *d'* which may make contact, *d* with any of the upper buttons and *d'* with any of the lower ones. In diagram 31*a*, we show end *d* of the field making contact with button *b* and end *d'* with button *b'*. The field is thus in parallel with the resistance and has impressed on it 240 volts. Maximum booster field current results and the booster generates the maximum voltage it is capable of, about 90 volts. The connections of the armature of the booster with respect to the exciter voltage (diagram 1) are however such that the booster bucks the exciter voltage and minimum generator field current results.

Now let the field be connected as in 31*c*, its *d* end to button *e* and its *d'* end to button *j*. The total current taken by the combined field and resistance will now enter at point *p*, flow through the resistance to *q* where it divides, part flowing through the field from *d* to *d'* and the remainder continuing through the resistance *q r t*. At *t* the two parts again unite to flow through the resistance *t n* and on to the negative bus.

The amount of current flowing through the field will now be less than before (actually, if the resistance be uniform, somewhat less than half its value in 31*a*). This follows if we consider that the voltage from *p* to *n* is 240 and due to the IR drop in sections *p q* and *t n*, the voltage from *q* to *t* must be

Diagram 31


Booster Field
Full Buck
Booster Field
Half Buck (approx)
No Field
Half Boost (approx)
Full Boost
Current in Resistance only
Current in Field only
Combined Current

less than this. The direction of the current is the same as before. The reduction in its field current causes the booster to generate less voltage and so the amount of buck is reduced and greater generator field current results.

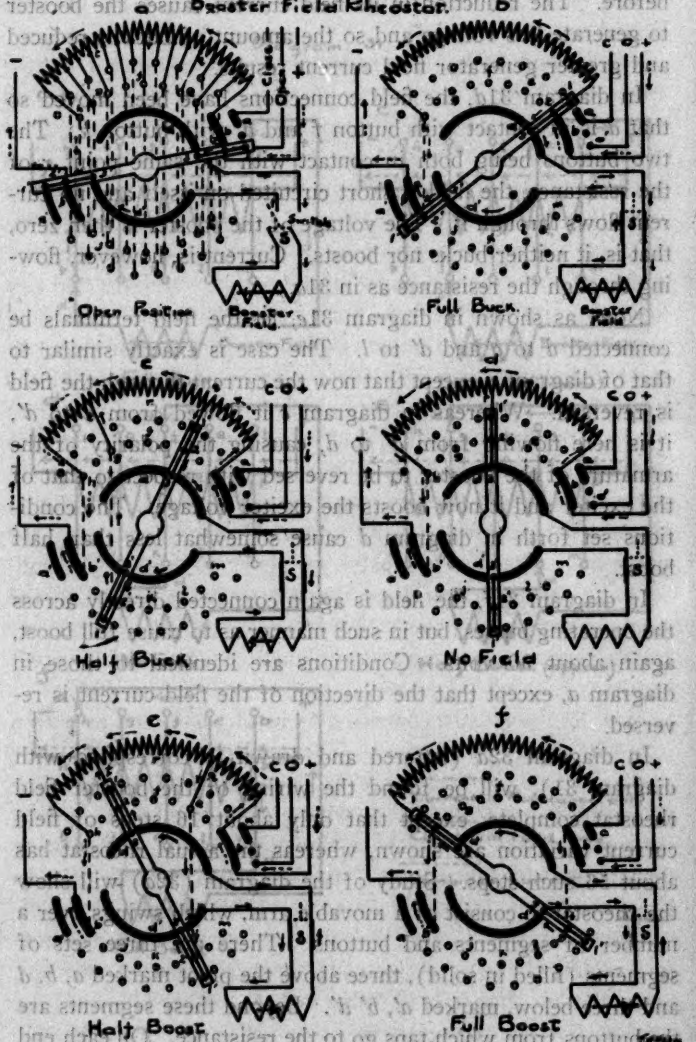
In diagram 31*d*, the field connections have been moved so that *d* is in contact with button *f* and *d'* with button *k*. The two buttons being both in contact with the same point *r* of the resistance, the field is short circuited on itself and no current flows through it. The voltage of the booster is then zero, that is, it neither bucks nor boosts. Current is, however, flowing through the resistance as in 31*a*.

Now, as shown in diagram 31*e*, let the field terminals be connected *d* to *g* and *d'* to *l*. The case is exactly similar to that of diagram *c*, except that now the current through the field is reversed. Whereas in diagram *c* it flowed from *d* to *d'*, it is here flowing from *d'* to *d*, causing the polarity of the armature of the booster to be reversed with respect to that of the exciter and it now boosts the exciter voltage. The conditions set forth in diagram *d* cause somewhat less than half boost.

In diagram 31*f*, the field is again connected directly across the operating busses, but in such manner as to cause full boost, again about 90 volts. Conditions are identical to those in diagram *a*, except that the direction of the field current is reversed.

In diagram 32*a* (lettered and drawn to correspond with diagram 31), will be found the wiring of the booster field rheostat complete, except that only about 16 steps of field current variation are shown, whereas the actual rheostat has about 56 such steps. Study of the diagram (32*a*) will show the rheostat to consist of a movable arm, which swings over a number of segments and buttons. There are three sets of segments (filled in solid), three above the pivot marked *a*, *b*, *d* and three below, marked *a'*, *b'* *d'*. Beyond these segments are the buttons from which taps go to the resistance. On each end of the arm are a set of contacts, each set connected together

Diagram 32.


Booster Field Rheostat.
a
b
c
d
e
f
Open Position
Booster Field
Full Buck.
Half Buck
No Field
Half Boost
Full Boost
S
CO+

and spaced so as to make contact with the segments and buttons beneath. The contacts on the upper end of the arm are marked 1, 2, 3 and those on the lower end, 1′, 2′, 3′. Below segment *a* are two buttons (black). The one adjoining segment *a* is dead and performs no function. The next one (covered by contact 1 in diagram 32*a*, but showing in diagram 32*b*) is marked *a′*.

From the upper buttons taps lead into the resistance, and corresponding buttons, top and bottom, are joined together. To segment *a* is connected the lead going to the closing coil circuits of the main field switches and to button *a′* is connected the lead going to the trip coil which opens the main field switches. Segment *b* is connected to the operating bus, from which the booster field is excited. To segments *d* and *d′* the booster field is connected, a switch *s* (mounted on a small separate panel over the main operating board) being inserted. Segment *b′* is connected to the negative operating bus and also to button *h*. Similarly segment *b* is connected to button *m*.

The movable arm is operated through bell cranks and rods by means of the pivoted field lever which moves out and down on the main operating board. When the lever is pushed up to the board, the arm of the rheostat is as shown in 32*a* and when pulled out and down as far as it will go, the rheostat arm is as shown in 32*f*.

Diagram 32*a* is the "field open" position, for as will be shown in part 3 B, the field switches are open, so that the generator field current is zero. Maximum current is however flowing through the field of the booster in such a direction as to give "full buck," the condition being that of diagram 31*a*. This can be seen by following the current through in diagram 32*a*. Starting from the positive terminal the current passes to segment *b*, to contact 2, contact 3, segment *d*, through the field in the direction of the arrows to segment *d′*, contact 3′, contact 2′, segment *b′* to the negative bus. This current flows through both booster fields as soon as the operating bus is energized from the exciter board. If a booster is not

to be used, the switch *s* is opened, although if the booster is running, it may have its field fully excited as shown in diagram 32*a*, without causing any over heating. Current also flows through the resistance from *b* to *h* to *b'*.

As soon as the arm is moved far enough over so that contact 1 makes connection with segment *a*, the field switches automatically close and the minimum value of generator field current results. Full buck continues as long as contact 2 is in connection with segment *b*, as shown in diagram 32*b*. In this and in succeeding parts of the diagram, only such portions of the rheostat connections are indicated as are carrying current. The path and strength of the booster field current is the same in both diagrams 32*a* and 32*b*.

As the arm continues to move over, the amount of buck is decreased by the insertion of resistance, allowing the generator field current to increase. In diagram 32*c* the field has been connected across section *q r t* of the resistance exactly as in diagram 31*c* and the condition of half buck results. The arm having moved so far as to have contact 2 in contact with button *e*, the path of the current is now from the positive bus to segment *b*, through the resistance to *q*, to button *e* (covered by the arm), to contact 2, contact 3, segment *d*, through the field to segment *d'*, contact 3', contact 2', button *j* (covered by arm), button *g*, *t*, through the resistance to button *h*, segment *b'* to the negative bus. Current also flows through section *q r t* of the resistance.

More and more of the resistance is gradually inserted as the arm continues to move over and the booster field current becomes smaller, reaching zero when the arm is in the mid way position, as shown in diagram *d*. This condition is exactly as in diagram 31*d*. No current flows through the field, as it is completely short circuited by the connection between buttons *f* and *k* (covered).

Further movement of the arm now gradually increases the field current from zero in the reverse direction. In diagram 32*e*, we have the condition of half boost, the current now

flowing from segment *b*, through the resistance to *q*, button *e*, button *l* (covered), contact 2′, contact 3′, segment *d*′, through the field to segment *d*, contact 3, contact 2, button *g*, *t*, through the resistance to *h*, segment *b*′ to the negative bus.

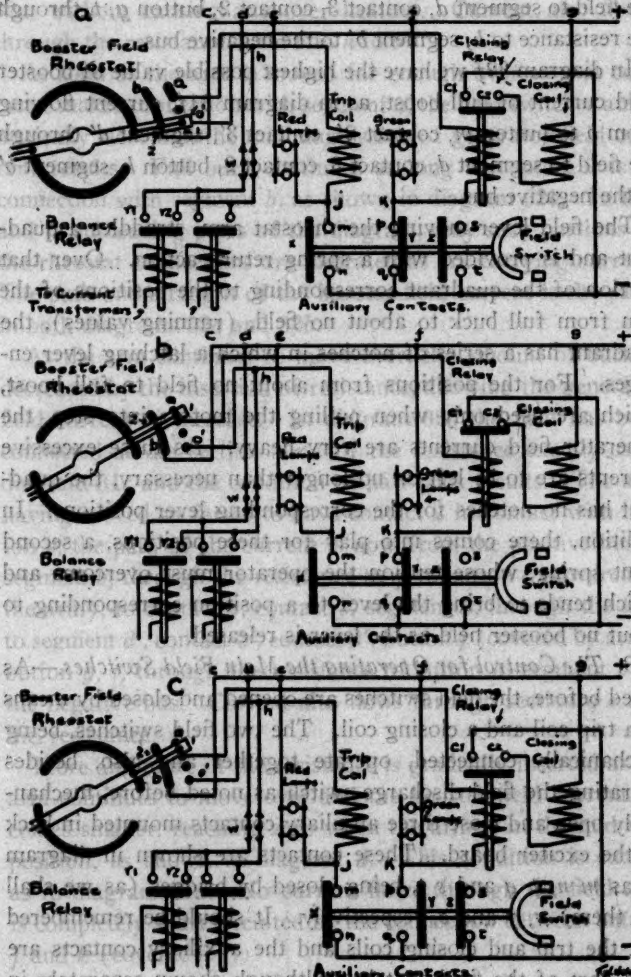
In diagram 32*f* we have the highest possible value of booster field current or full boost, as in diagram 31*f*, current flowing from *b* to button *m*, contact 2′, contact 3′, segment *d*′ through the field to segment *d*, contact 3, contact 2, button *h*, segment *b*′ to the negative bus.

The field lever moving the rheostat arm, straddles a quadrant and is provided with a spring return action. Over that portion of the quadrant corresponding to the positions of the arm from full buck to about no field, (running values), the quadrant has a series of notches in which a latching lever engages. For the positions from about no field to full boost, which are used only when pulling the motors into step, the generator field currents are very heavy. As these excessive currents are to be left on no longer than necessary, the quadrant has no notches for the corresponding lever positions. In addition, there comes into play for these positions, a second stout spring, whose tension the operator must overcome and which tends to bring the lever to a position corresponding to about no booster field as the lever is released.

B. The Control for Operating the Main Field Switches.—As noted before, the field switches are opened and closed by means of a trip coil and a closing coil. The two field switches, being mechanically connected, operate together and also, besides operating the field discharge switch as noted before, mechanically open and close three auxiliary contacts mounted in back of the exciter board. These contacts are shown in diagram 33 as *m n*, *p q* and *s t*, being closed by bridges (as we shall call them) *x*, *y* and *z*, respectively. It should be remembered that the trip and closing coils and the auxiliary contacts are all a part of the field switches, although shown separately in the diagrams. In diagram 33 only that portion of the booster

Diagram 33.

Field Switch Opening and Closing Circuits



field rheostat involved is shown and only two of the six sections of the balance relay.

In part *a* of the diagram is given the situation when the operator is ready to start up the motors, the generators and exciters being assumed as up to speed. This position of the booster field rheostat was referred to before as the "no field" position and it is obviously properly so called, as the field switches are open. There are six circuits involved, starting from points *c*, *d*, *e*, *f* and *g*, from the positive connection to the operating bus. The first circuit starting from *c* and continuing through segment *b*, contact 2, contact 1, point *h* to the trip coil, is open at *m*. The closing relay circuit, also starting at *c*, is open at *a*. The balance relay circuit, starting at *d*, is open at *r*1. The red lamp circuit, starting at *e*, is open at *m*, and the closing coil circuit, starting at *g* is open at contacts *c*1. The green lamp circuit, starting at *f*, is closed through *p q* and these lamps (mounted close to the field lever) are burning, indicating to the operator that the field switches are open.

The field lever is now pulled out by the operator and this act moves the rheostat arm so that contact 1 makes contact with segment *a* (diagram 33*b*). This closes the circuit through the closing relay, current flowing from *c*, through segment *b*, contact 2, contact 1, segment *a*, the winding of the closing relay, *k*, contact *p*, bridge *y*, contact *q* to the negative side of the operating bus. As soon as current flows through this circuit, the closing relay functions, bridging the contacts *c*1 and *c*2 and energizing the closing coil, its current flowing then from *g*, through the coil, contacts *c*1 and *c*2 to the negative line. This current causes the closing coil to close the generator field switches against spring tension and minimum generator field current results. The field switches in closing also operate the auxiliary contacts and in diagram 33*c* the situation after the field switches are closed is presented. Contacts *p q* are now open and contacts *m n* and *s t* closed. Opening contacts *p q* opens the circuit through the closing relay, which, as soon as its plunger drops, also opens the circuit through the closing

coil. As mentioned in part 1E, the field switches are held closed by a latch. The circuit through the green lamps is also broken when contacts *p q* are opened. The closing of contacts *m n*, prepares the trip coil circuit and also closes the red lamp circuit. The fact that these are burning indicates to the operator that the field switches are closed. The operator now continues to move the rheostat arm to give the required field current to the generator.

If the operator moves the rheostat arm very rapidly over contact *a*, the field switches will not close. This is due to the fact that the closing relay circuit is broken by contact 1 and segment *a* parting company before the switches are entirely closed. The relay drops out and opens the closing coil circuit. However, nothing is gained by haste, as the field of the booster will not build up instantaneously due to its self-inductance. It is also evident from this that the design of the auxiliary contacts must be such that they will not operate before the field switches are fully closed, so that the latches take hold.

When the motors are to be stopped, the operator brings the rheostat arm back as far as it will go, making contact with button *o'*. The trip coil circuit is now closed, current flowing from *c*, through segment *b*, contact 2, contact 1, *o'*, *h*, the trip coil, *j*, *m* and *n*, to the negative connection. The trip coil functions and knocks out the latch holding the field switches closed against spring tension. The field switches in opening, operate their auxiliary contacts and we again have conditions as in diagram 33*a*, the trip coil and red lamp circuits being broken by the opening of contacts *m n* and the green lamp circuit being closed by contacts *p q*.

The reason for using a separate closing or control relay is that the amount of current necessary to operate the closing coil is considerable and its handling is better effected by a relay designed with special contacts. The relay and trip coil currents are small, so that they can readily be handled at the auxiliary contacts. The closing coil must close the switches

against fairly heavy spring tension while the trip coil need only deliver a sharp blow to the field switch latch.

The operation of the balance relay is evident from diagram 33*c*. Should balance be destroyed through a short circuit or other reasons and a plunger be pulled down, current flows from *d*, across contacts *r*1, *r*2, through *h*, the trip coil, *j*, contacts *m n* to the negative line. It is of course obvious that the relay need only function when the field switches are closed and contacts *m n* made.

C. The Electrical Interlocks.—The electrical interlocks on the generator and motor disconnecting switches and the cell doors are controlled by the field switches. Those on the motor reversing and pole changing switches are controlled by the under-current relay. The simplified wiring of the circuits of the port side is given in diagram 34.

On the generator disconnecting switch are mounted two auxiliary contacts AX, one of which is mechanically closed by the switch in either high or low voltage position. In the diagram, if the switch G.D.S. is closed to the left, contacts *a b* and *c d* are closed by the left hand bridges, while if the switch is thrown to the right, contacts *a'* *b'* and *c'* *d'* are closed. Contacts *a b* and *a'* *b'*, as well as contacts *c d* and *c'* *d'* are in parallel, respectively, so that the result is immaterial which way the generator disconnecting switch is thrown. Following from the positive operating bus tap, +, we pass to the contact *c* from which we have two parallel circuits. One passes through contacts *c d*, to contact *d'*, to *f*, through the parallel combination of the interlocking coils of the two port motor disconnecting switches M.I.C. and the interlocking coil C.D. of the port cell door. After passing through these coils, the circuit continues to the point *g*, up through contacts *a b* to *e*. Leaving this circuit for the moment at *e*, let us trace the other parallel circuit from *c*. This passes through the interlocking coil of the generator disconnecting switch G.I.C., to *e*, so that we have between the points *c* and *e*, one circuit through the auxiliary contacts of the generator disconnecting switch and the

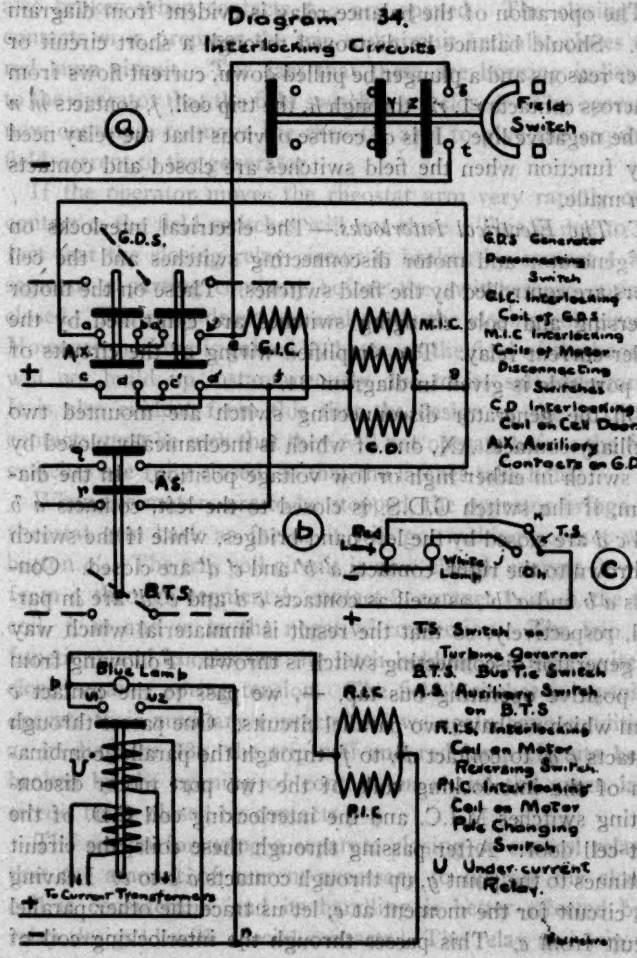


Diagram 34.
Interlocking Circuits
Field Switch
G.D.S.
A.X.
G.I.C.
M.I.C.
C.O.
A.S.
B.T.S.
Red Lamp
White Lamp
T.S.
Blue Lamp
U
To Current Transformers
G.D.S. Generator Disconnecting Switch
G.I.C. Interlocking Coil of G.D.S.
M.I.C. Interlocking Coils of Motor Disconnecting Switches
C.O. Interlocking Coil on Cell Door
A.X. Auxiliary Contacts on G.D.S.
T.S. Switch on Turbine Governor
B.T.S. Bus Tie Switch
A.S. Auxiliary Switch on B.T.S
R.I.C. Interlocking Coil on Motor Reversing Switch.
P.I.C. Interlocking Coil on Motor Pole Changing Switch
U Under-current Relay.
To Motors

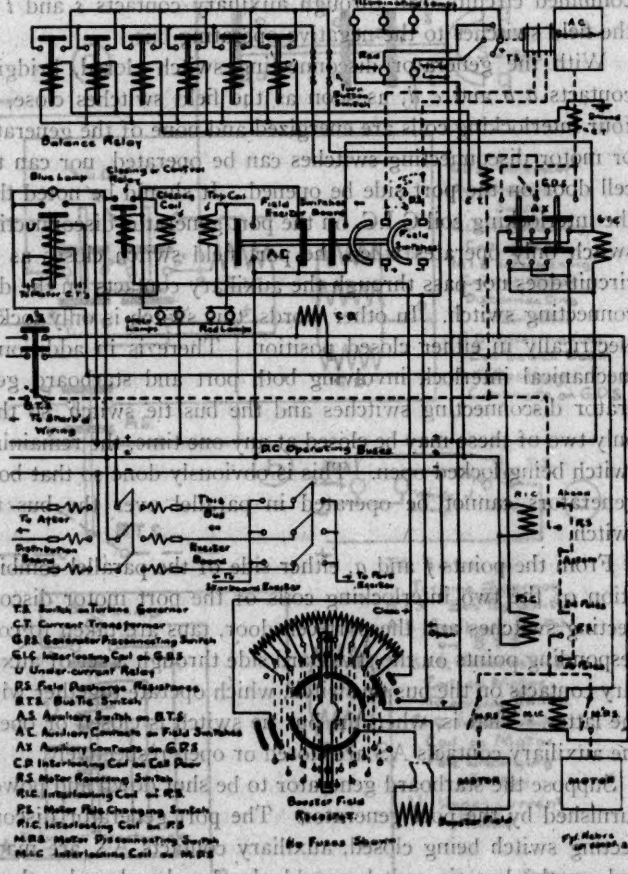
interlocking coils of the port motor disconnecting switches and the port cell door and a second circuit through the interlocking coil of the port generator disconnecting switch, which does not pass through the auxiliary contacts of the latter. From *e* the combined circuits lead through auxiliary contacts *s* and *t* of the field switches to the negative operating bus.

With the generator disconnecting switch closed, bridging contacts *a b* and *c d*, as soon as the field switches close, all four interlocking coils are energized and none of the generator or motor disconnecting switches can be operated, nor can the cell door on the port side be opened. It should be noted that the interlocking coil G.I.C. on the port generator disconnecting switch only operates when the port field switch closes as its circuit does not pass through the auxiliary contacts on the disconnecting switch. In other words, this switch is only locked electrically in either closed position. There is in addition a mechanical interlock involving both port and starboard generator disconnecting switches and the bus tie switch, so that only two of these may be closed at any one time, the remaining switch being locked open. This is obviously done so that both generators cannot be operated in parallel over the bus tie switch.

From the points *f* and *g*, either side of the parallel combination of the two interlocking coils of the port motor disconnecting switches and the port cell door, taps are taken to corresponding points on the starboard side through a set of auxiliary contacts on the bus tie switch, which operate together with the latter. That is, when the bus tie switch is closed or open, the auxiliary contacts AS are closed or open respectively.

Suppose the starboard generator to be shut down and power furnished by the port generator. The port generator disconnecting switch being closed, auxiliary contacts AX are made and, as the bus tie switch would also be closed under these circumstances, auxiliary contacts AS are also closed. Now when the port field switches close, all the port interlocking circuits are energized as first described. The auxiliary busses

Diagram E.
Complete Control Wiring



q and *r*, being connected to points *f* and *g*, have across them the same voltage (operating bus voltage) as is impressed on the interlocking coils of the port motor disconnecting switches and the port cell door. Since the corresponding interlocking coils on the starboard side are also connected across the auxiliary busses *q* and *r*, they, too, will close when the port field switch closes. Or the other way around, if the starboard generator only is furnishing power, as soon as the starboard field switch closes, operating bus potential appears across auxiliary busses *q* and *r* and therefore energizes the three coils between the points *f* and *g*.

Obviously this must be done. If only one generator is supplying power, all four motor disconnecting switches and both cell doors must be locked. If both generators are being used, each takes care of the interlocks on its own side.

The interlocking coils on the reversing and pole changing switches are operated together in similar fashion by the under-current relay. As soon as current flows to the motors, the under-current relay closes the circuits to the interlocking coils and lights its blue lamp. From the positive tap to the operating bus, current flows across contacts *u*1 and *u*2, to *p*, where it divides, part flowing through the lamp to *n* and the remainder to *m*, through the interlocking coils to *n* where it unites with the lamp current and returns to the negative tap from the operating bus.

D. The Steam Limit Device.—In turbine or reciprocating engine ships, when the rudder is put over, no difficulty so far as the propulsion machinery is concerned, is experienced. Although the engine room may be informed of the fact, no further attention is paid to the result of one engine slowing down and the other speeding up. As is known, when a ship executes a turn, say to starboard, the load is increased on the starboard engine and lessened on the port side, but inasmuch as no change is made in the throttle setting, the starboard side slows down due to the increased load, while the port engine speeds up.

In an electrically propelled ship, conditions result which must be specially taken care of. We have first a turbine whose steam supply is under control of an automatic speed governor. When the speed of the unit changes from a given setting, the governor changes the steam supply until the speed is back to normal. It is also a characteristic of the induction motor that it operates within a per cent or two of a given speed for all conditions of load. Or, put in other words, the speed of the propellers is fixed whether they are submerged or entirely out of water. The load on the generators under such limits, varies tremendously and the variation of current taken by the motors will be very wide, as the motors will take power from the generators as their load requires. If the ship makes a turn to starboard, the load on the port motors is lessened and they will take considerably less power from the generator. The starboard motors, however, due to their efforts to operate at the same speed as before, are apt to be so much overloaded as to fall out of step, at the same time drawing heavily on the generator. The condition is much aggravated when both generators are in use and when a turn (say to starboard) is made at high speed, the starboard turbine will draw an excessive amount of steam because its governor causes greater opening of the steam admission valves in following its characteristic of maintaining constant turbine speed.

The turbine governor is of a type which might be termed adjustable. It may be set from the main switchboard to hold the turbine speed constant at any desired value from about 400 to 2,100 r.p.m. If the operator desires, say, 1,500 r.p.m. on the generator, he adjusts the speed lever by means of a handwheel and the governor holds the speed to 1,500 turns independently of the load on the generator. Now this characteristic of steady speed is a valuable one, particularly in keeping station in formation, but as has been explained above, it introduces the feature of drawing large additions of power in making turns, which must be eliminated. This is accomplished by the setting from the main control board of the steam limit,

which is simply an adjustable stop on the governor, controlled by a lever moving over a notched quadrant on the main board. When the governor in its efforts to admit more steam, comes up against this stop, no more steam can be admitted. The stop does not, however, limit the governor from reducing the amount of steam. As stated, the stop is adjustable and carries with it two electrical contacts. The first of these is closed by the governor arm when it is about half an inch from the stop, lighting up a white lamp on the main board. When the governor arm is about one-eighth inch from the stop, the second contact is made in addition and both red and white lamps burn. Finally, when the governor has moved up as far as the stop permits, only the red lamp is burning. Thus, when the ship makes a turn, the amount of steam cannot increase so the turbines and motors slow down as the load increases. When the white lamp only burns, which is the position used for steady operation, the operator knows that he has ample steam margin for constant speed with the usual small variations of load. If both white and red lamps burn, his margin is small and should only the red lamp burn he has no margin whatever. In a rough sea the lamps will flicker with the pitching of the ship, meaning that speed remains constant as load varies, which is another way of saying that racing of propellers does not occur.

In maneuvering the operator must take care to know his steam limit setting. Occasions arise where the limit setting must be changed during the operation, as in reversing. If the ship were going ahead 15 knots and the steam limit set on the white light and the signal for full speed astern is received, it is necessary to raise the steam limit setting in order to apply full power. This is done by the operator while waiting for the under-current relay to open. Under ordinary conditions the signal lamps always keep the operator advised.

LOW PRESSURE TURBINE BLADING FAILURES IN DESTROYERS.

By Lieut.-Comdr. D. F. Ducey, U. S. N., Member.

On what might be termed the War Program, the following destroyers, equipped with impulse type turbines, were built: 79-86, 95-102, 103-112, 161-170, 171-180, 251-260, and 261-295.

With the exception of a few minor items, the machinery installations of these vessels are identical, the approved plans for group 79-86, with developments and a certain few changes, having been used for all the succeeding groups.

The main propelling units of each destroyer consist of eight impulse type turbines, these turbines, through reduction gearing, driving the two main shafts with their attached propellers. The turbine installation, itself, consists of one high pressure, one intermediate pressure and one low pressure turbine in each engine room compartment. The high pressure and intermediate pressure turbines are in tandem, being connected by a slip coupling; the intermediate being connected to the so-called high pressure pinion by another slip coupling. The low pressure turbine, located inboard of the high and intermediate, through a slip coupling connection, drives the low pressure pinion. Figure I shows the general arrangement.

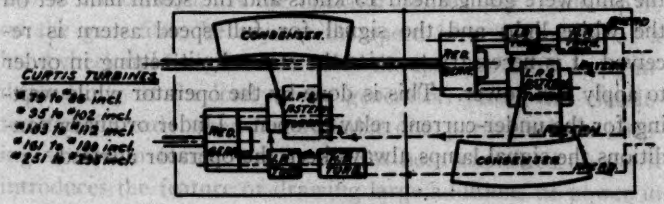


Fig. I.

When operating at full power, about 27,000 horsepower, live steam is admitted to the high pressure turbine steam chest, and after expanding in the first stage, one-sixth of the flow passes through the high pressure turbine, the remaining five-sixths passing to the steam chest of the intermediate pressure turbine. Steam from the high and intermediate pressure turbines expands into the low pressure turbine and is then discharged to the condenser.

The astern turbines, one for each shaft, are fitted in the same casings, and on the same shaft, as the low pressure ahead turbines and are capable of driving the vessel astern at a speed of twenty knots.

The main units are located symmetrically in each engine room; the high and intermediate turbines being outboard in each engine room and the low pressure turbines very close to the center line. The port main shafting, forward engine room, is 95 feet 4¼ inches, and the starboard main shafting is 67 feet 3¼ inches in length.

From the above it can be seen that there is nothing unusual in the arrangement of the units and that, with the exception of the greater length of the port line shafting, the port and starboard low pressure turbines can be considered as operating under like conditions.

The low pressure turbines are of the impulse type, having five rows of moving blades. Between rows are diaphragms, in halves, carrying the nozzles. The first and second rows are of monel metal and the third, fourth and fifth rows are of steel; these blades for groups 79-86, 95-102 and 103-112 being specified of chrome-vanadium steel and for groups 161-170, 171-180 and 251-295, of chrome-nickel steel. The blades are of the usual impulse type section and of the following lengths:

1st stage	7.281 inches.
2nd stage	9.281 inches.
3rd stage	11.281 inches.
4th stage	12.281 inches.
5th stage	13.781 inches.

The active portion of the blade is approximately 1¾ inches less than the overall length.

The low pressure rotor shaft, of forged steel, is 6 feet 8 inches between centers of journals. The fifth stage wheel is 66 7/16 inches in diameter over tips of blades; pitch circle, 54 inches in diameter.

At full power the propellers make about 450 revolutions per minute; the corresponding speed of the low pressure turbine is about 3,000 revolutions per minute. The test speed is 25 per cent in excess of this and rotor wheels were spun accordingly. All tests were satisfactory.

The first destroyer of the 79-86 group was delivered on April 6, 1918, the remaining destroyers of this and the next group, 95-102, following at short intervals during the spring and summer of 1918. In so far as the main propelling units themselves were concerned, these vessels not only successfully completed their trials but have, in addition, cruised thousands of miles, under the varying and the exacting conditions required during war service, without a single blade failure of the kind under discussion.

While stripping turbine blading is not an unheard of occurrence, it certainly is not a common accident, especially where impulse blading is concerned; and, as a rule, when such an accident does happen, it is usually possible to arrive quickly at a definite conclusion as to the reason therefor. Therefore, in the late summer of 1919 when certain failures of low pressure turbine blading occurred, and there existed much uncertainty as to the causes of these failures, a systematic investigation was undertaken.

The first vessel investigated was the No. 104, which was delivered to the Government on November 11, 1918. Sometime after commissioning, while cruising at 25 knots, a blade, or several blades, in the second stage of the starboard low pressure turbine, carried away. Whether or not the resulting condition was caused by just one blade letting go and

tearing the others loose, or several blades going at the same time, could not be ascertained. Shortly after this accident, on August 26, 1919, while running a full power trial off Newport, R. I., six blades in the second stage of the port low pressure turbine carried away. The turbine was opened and a careful examination made, but, as everyone knows, examining a stripped turbine is an undertaking of some magnitude, the general appearance being similar to a cubist picture with a couple of puzzle pictures painted over it. However, a careful search for foreign objects did not yield anything and, as far as could be ascertained, the clearances had been properly adjusted and the operation had not been abnormal. The workmanship was examined and, while it could have been improved upon, there was nothing apparent that one could say caused the accident. These assumptions being eliminated certain of the blades were cut up and the metal examined. The examiner's report was to the effect that the metal, in its then present state, was unsuitable for turbine blading, a conclusion that seemed to be borne out by other information that came to light about this time, it being rumored that certain of the blades for the 251-295 group, subsequent to the forging process, had been reformed and that during this process the metal was weakened. As a matter of fact it turned out later that no definite information could be obtained on this particular point. However, while there was no reason to doubt the existence of defective metal in the 104's blades, there were other facts involved that made it advisable to continue the investigation.

As far as could be ascertained all blades for the 104's low pressure turbines were from the same stock and were manufactured at the same place and under like conditions; if some few blades failed from weakness of material, it could be expected that all should fail, as like conditions existed. However, the other blades did not fail. Moreover, it was a matter of record that thirty-two exactly similar turbines, like material and like manufacture, had functioned over a long period with-

out a single blade failure. Also, following the 104, similar failures, that is, individual blades carrying away, occurred as per the list below:

Destroyer Number	Location of Blade Failures — Turbine	Stage
104	S.L.P.	2
104	P.L.P.	2
173	P.L.P.	2
175	P.L.P.	3
176	P.L.P.	1
176	P.L.P.	2
178	P.L.P.	3
256	P.L.P.	2
272	P.L.P.	5
274	S.L.P.	4
280	P.L.P.	2
281	S.L.P.	3
281	P.L.P.	3
283	P.L.P.	2
284	P.L.P.	1
284	P.L.P.	4
285	P.L.P.	3
285	P.L.P.	2
285	P.L.P.	5
286	S.L.P.	3
286	P.L.P.	3
289	S.L.P.	2

Designating by groups:

Group	Failures	Location and Number of Blade Failures — Turbine	Number-Stage
79– 86	0	.....	...
95–102	0	.....	...
103–112	2	S.L.P.	1–2
		P.L.P.	1–2

Group	Failures	Location and Number of Blade Failures	
		Turbine	Number-Stage
161–170	0	.....	...
171–180	5	P.L.P.	2–2
			2–3
			1–1
251–260	1	P.L.P.	1–2
261–295	14	4 S.L.P.	1–2
			2–3
			1–4
		10 P.L.P.	1–1
			3–2
			3–3
			1–4
			2–5

Designating by turbines:

Turbine	Failures
S.L.P.	5
P.L.P.	17

Designating by stages:

Stage:	1st	2d	3d	4th	5th
Failures:	2	9	7	2	2

As these failures occurred, in each instance, all the possible available data was obtained. This data was carefully compiled, but it was not until the early fall of 1920 that an actual clue appeared.

The port low pressure turbine of the 280 was being rebladed by the *Vestal*. In conjunction with the work the Commanding Officer made the following report:

"There is forwarded under separate cover one of the turbine blades of the 3d stage of the main low pressure turbine of the 280, which is now on board the *Vestal* for reblading of the 2d, 3d and 4th stages.

"The above blade is forwarded for the information of the Bureau. The reblading of this turbine shows that the new blades of the different stages are not all alike, but vary in the following particulars:

(*a*) Length of blade.
(*b*) Thickness of root.
(*c*) Irregular position of tip.
(*d*) Shape of blade.

"In regard to (*a*), a few of the blades have been found to be shorter than standard. Regarding (*b*) some of the blades show different thickness of the root, and as a result it has been impossible to install the number of blades called for by the blue print. For instance, on the second stage which is now completed, the blue print calls for 288 blades, while it has been possible to use only 282 blades. Regarding (*c*) there are many blades where the tip is not central, being well over to one side or the other, this making it difficult to put the shrouding in place. Regarding (*d*) there are quite a number of blades which are bent forward or back, or to one side or the other. The blade being forwarded has quite a bend to one side.

"These same difficulties were experienced in the monel metal blades of the 2d stage, which have already been put in place. These blades, however, were quite pliable and could be moved slightly so as to line them up and put the shrouding on. The steel blades of the 3d stage, of which sample forwarded was one, are not so pliable, and in an effort to move this blade so that the tip would fit into the slot of the shrouding, it snapped off. But very little force was used to move it and it seems to be very brittle. The dents and burrs on the root were made in getting it off the turbine after it was broken.

"Another irregularity noticed is in the shrouding. Many of the holes are not uniformly spaced, and the line of holes is seldom parallel to the edges of the shrouding.

"It is believed that this may throw some light on the trouble which a number of the destroyers are having. The blades and shrouding were received from the Mare Island Navy Yard."

About five months previous to the failure of the turbine blading on the 280, the port propeller was damaged and from that time on considerable vibration existed in the port shafting and turbine. The port propeller was removed and repaired and the vibration eliminated to some extent. However, as the dock trial showed there was still some vibration remaining, the 280, just previous to the time the blades failed, put out to sea and operated at various speeds to test out the shafting in deep water under service conditions. During this trial spin everything ran all right and the 280 returned to port. A few days later, while warming up to get under way, trouble was experienced with the port low pressure turbine and investigation showed fifteen blades carried away in the first stage. Apparently the blading had failed while warming up along side the dock, but of this there was no proof. The blading may have failed during the run at sea several days before, as there are instances on record, in the case of the turbines in question, where stripping has occurred and not been discovered until the casings were lifted for other reasons; there being no indication at the time of the accident of anything out of the ordinary happening. This statement may appear a little out of the ordinary, in fact, the writer himself doubted it at first, but a rigid investigation showed it to be true.

On October 26, 1920, the Commanding Officer of the *Vestal* further reported:

"There are forwarded under separate cover, blades from the 3d, 4th and 5th stages of the 280's main low pressure turbine, in accordance with reference (*a*). There are no undamaged blades available as, in order to expedite removal of the old blades from the rotor, the blades were first cut off by means of an oxy-acetylene cutting torch. The roots were then driven off by a pneumatic hammer. The best blades and some of the blade roots have been selected.

"In addition, there is also forwarded a new blade which broke while installing on the 4th stage. The cause of this break is evidently brittleness. This blade was received from the Mare Island Navy Yard.

"There is also forwarded one new blade and piece of shrouding in the exact condition in which it was received from the Navy Yard. If the root of this blade is placed against a straight surface in an upright position and the angle of the shrouding noted, it will show the Bureau a condition which has been contended with in reblading these stages. This is however an extreme case and such blades and shrouding are being discarded as bad. All of the blades and shrouding, however, show, to a greater or less degree, irregularities of this nature.

"All blades are being tested before they are secured in place so as to reduce the chances of installing any particularly brittle or defective blades."

From the above and other available data the following facts were established:

(*a*) Seventeen of the failures occurred in the port low pressure turbines and five in the starboard low pressure turbines. The reason for the greater number of failures in the port turbine has not been established and is a subject for further investigation. A theory involving vibration and the greater length of the port line shafting has been advanced, but this can remain an open problem for the present.

(*b*) The greatest number of failures occurred in the 261-295 group. The blading of these turbines was accomplished at a government turbine plant, which plant was built by the Government and placed under the management of the firm holding the contracts for the construction of the destroyers involved.

(*c*) The blades for the 261-295 group were forged from stock supplied by one of the large steel corporations.

(*d*) Failures in stages were as follows: 1st stage, 2; 2d stage, 9; 3d stage, 7; 4th stage, 2; 5th stage, 2.

(*e*) The primary failure as far as could be ascertained, involved but one or two blades in a single stage. In instances from one to fifteen blades in a single stage were found stripped, but indications were that the failing of one or two blades was the cause of the others going. In no case was there any indication of a general failing of the blades, the damage usually being confined to the blades being held by a single section of shrouding.

(*f*) Practically all of the blades ruptured across the root section, although in instances, where there was a tearing action by the shroud band and loose blades, the rupture occurred higher up on the blade.

(*g*) In only one instance, that of the 280, did serious vibration exist previous to the blades failing.

(*h*) In certain instances, the fact that blades had stripped was not discovered until sometime after the occurrence, when the casings were being lifted for other reasons. In the ensuing interval the turbines operated satisfactorily.

(*i*) In such cases, see (*h*), while there was no excessive vibration due to the loss of the blades, in those instances where the stripping was discovered at the time of its occurrence, as a rule a very noticeable vibration became evident immediately.

(*j*) Sometimes, when the failure occurred in the earlier stages, the ruptured blade or blades, in going through the following stages, tore blades out of these stages; in other instances the ruptured blade or blades went through as many as three stages and the intervening diaphragm nozzles, without tearing loose other blades. It would be expected that in such cases one would find the blades in the stages intervening between the stripped section and exhaust space, badly chewed up, but such was not always the case. The "chewing-up" was usually of minor importance and in some cases but five or six blades per stage were involved. As a rule the diaphragm nozzles were easily straightened and but one case of extensive renewals being necessary can be recalled. Incidentally this speaks well for the ruggedness of the turbine design.

(*k*) Certain blades that failed showed evidence of cracks having existed in the vicinity of the root sections.

(*l*) The root sections were not uniform, they varied between wide limits.

(*m*) In some cases the ruptured blade tore loose from the shroud band; in other instances the blades, even after rupture, failed to tear loose from the shroud band.

(*n*) In no instance was the material of the shroud bands found to be defective.

(*o*) The holes in certain of the shroud bands were not cut true to the center line, but were staggered.

(*p*) Many of the blades, instead of being true, were slightly bent.

With the above information available, the U. S. Naval Engineering Experiment Station at Annapolis, Md., was directed to undertake an investigation to determine the condition of the metal of the blades and to determine the cause of the repeated failures.

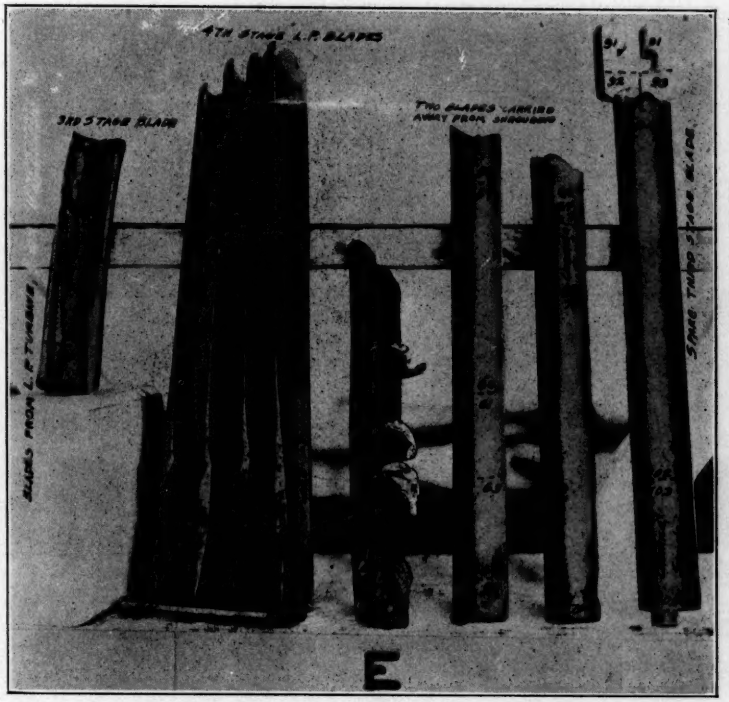
The material examined consisted of blading from the 178, the 175, and the 280. See E to H, inclusive.

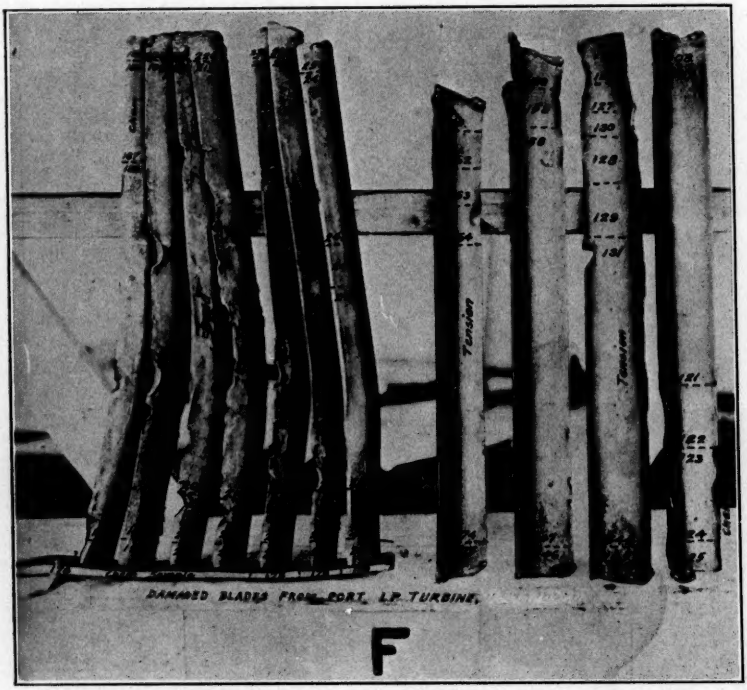
The material from the 175 came from the damaged port low pressure turbine, see E, and consisted of:

1 broken blade from the 3d stage.
1 spare blade for the 3d stage.
2 blades which broke off from the shrouding, and the corresponding section of shrouding.
Damaged blades from the 4th stage.

The material from the 178, see F, came from the damaged port low pressure turbine and consisted of a section of damaged blading, including shrouding.

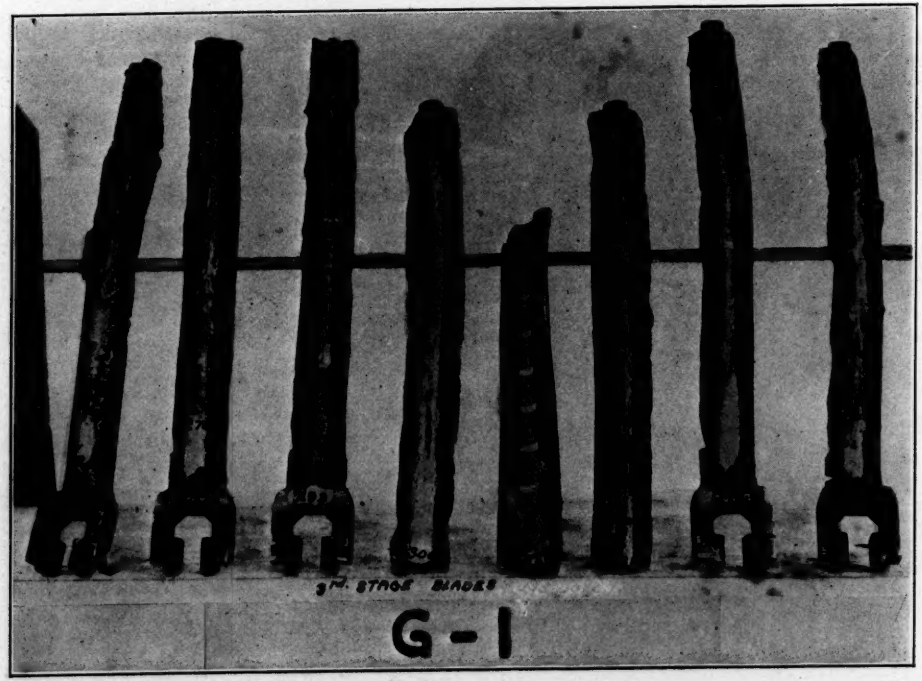
The material from the 280 came from the damaged port low pressure turbine and consisted of; a number of broken and damaged blades from the 3d stage, see G-1 and G-2, damaged blades and blade roots from the 3d, 4th and 5th stages,


4TH STAGE L.P. BLADES
3RD STAGE BLADE
TWO BLADES CARRIED AWAY FROM SHROUDING
SPARE THIRD STAGE BLADE
BLADES FROM L.P. TURBINE
E

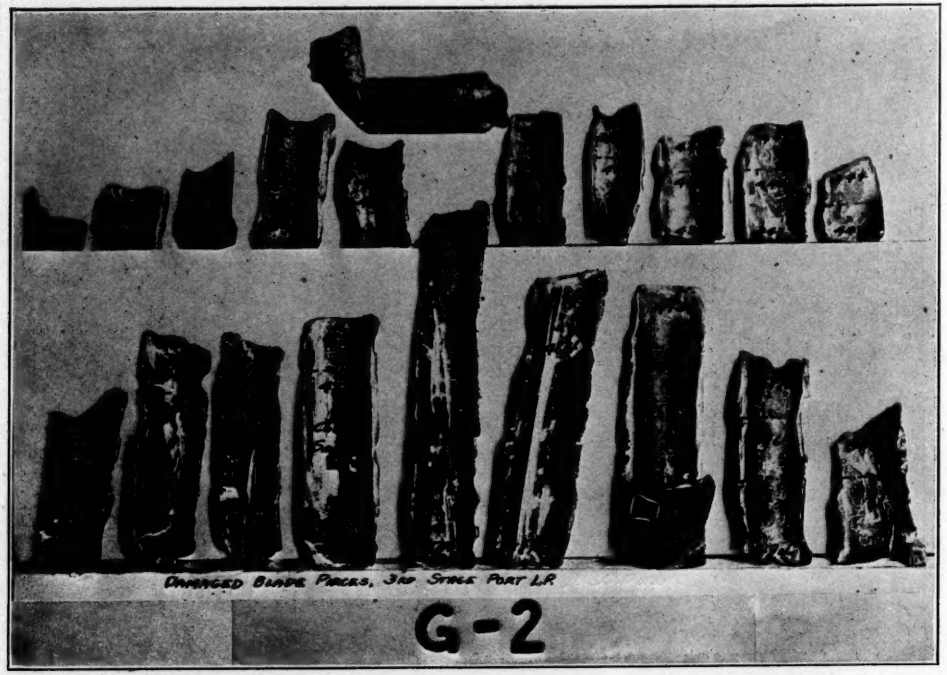


DAMAGED BLADES FROM PORT L.P. TURBINE.

F

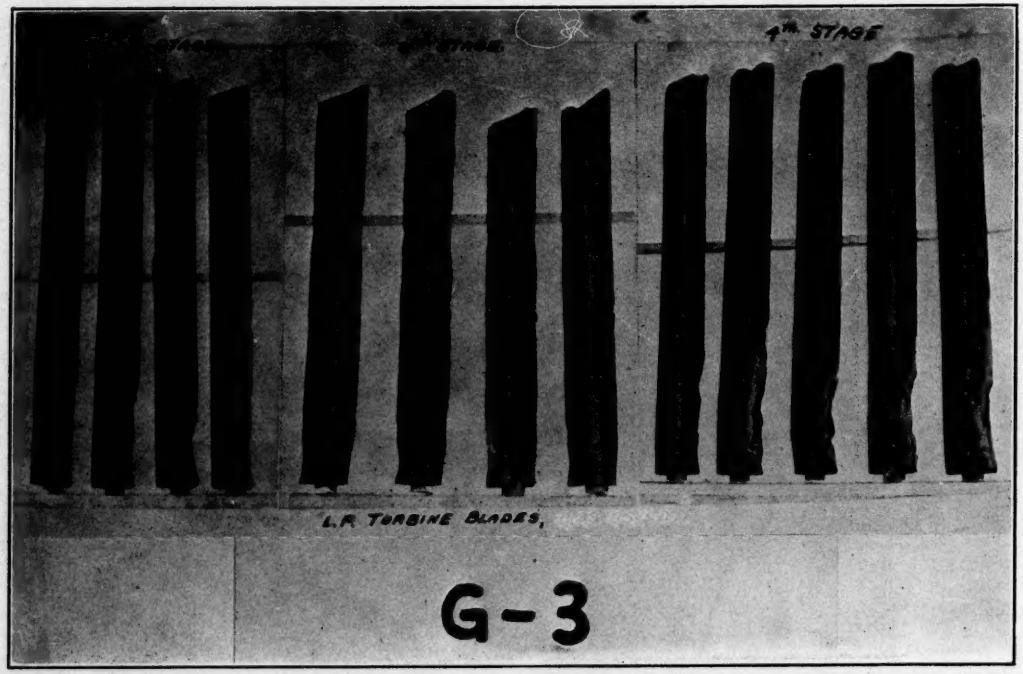


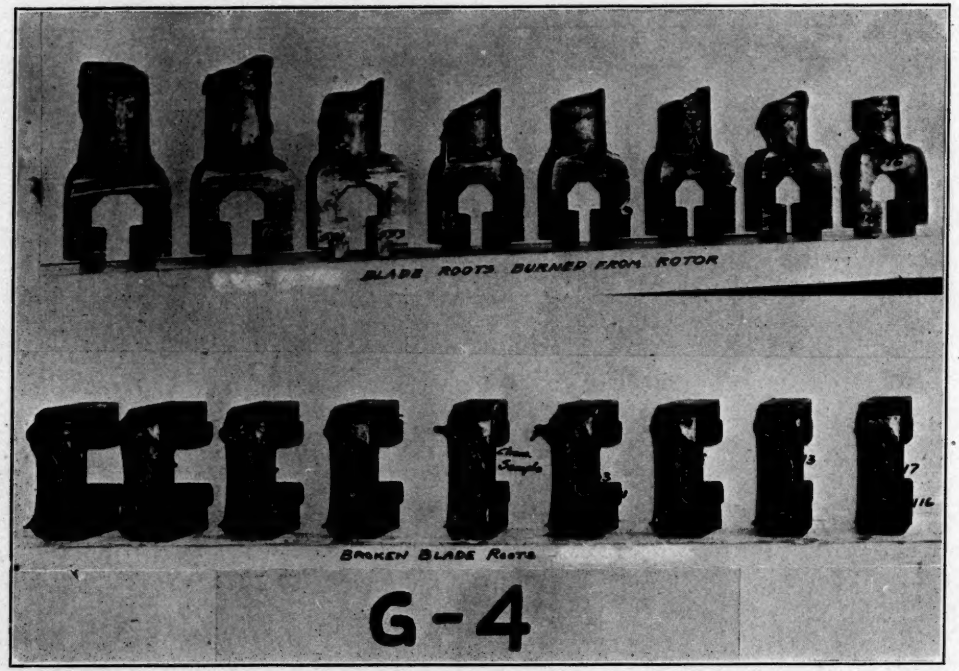
G-1

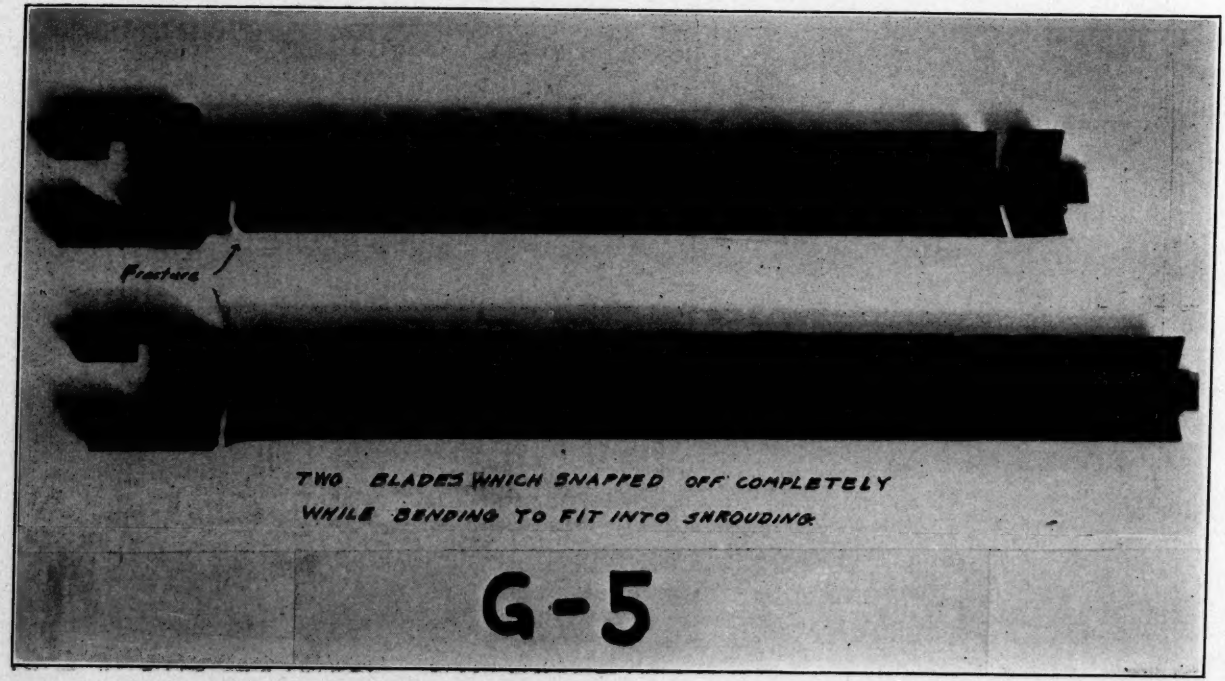


DAMAGED BLADE PIECES, 3RD STAGE PORT L.P.

G-2

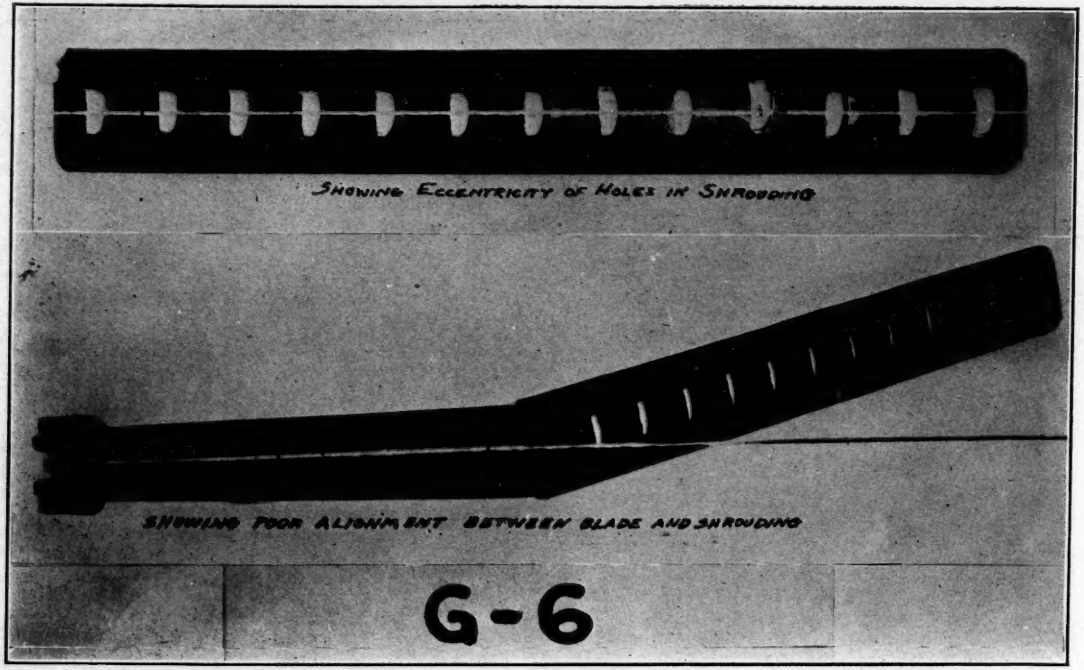

4th STAGE
L.P. TURBINE BLADES,
G-3


BLADE ROOTS BURNED FROM ROTOR
BROKEN BLADE ROOTS
G-4



TWO BLADES WHICH SNAPPED OFF COMPLETELY
WHILE BENDING TO FIT INTO SHROUDING.

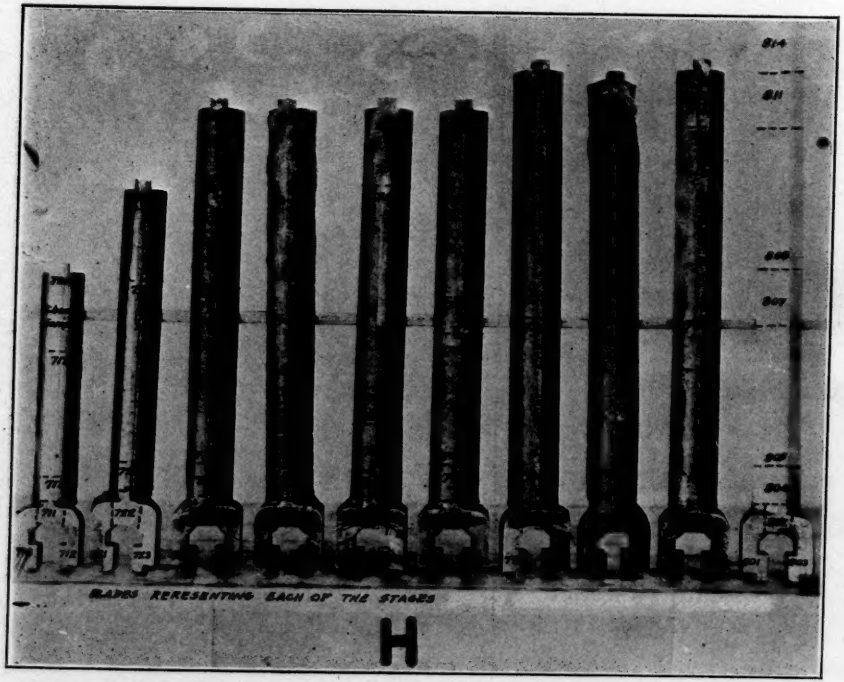
G-5



SHOWING ECCENTRICITY OF HOLES IN SHROUDING

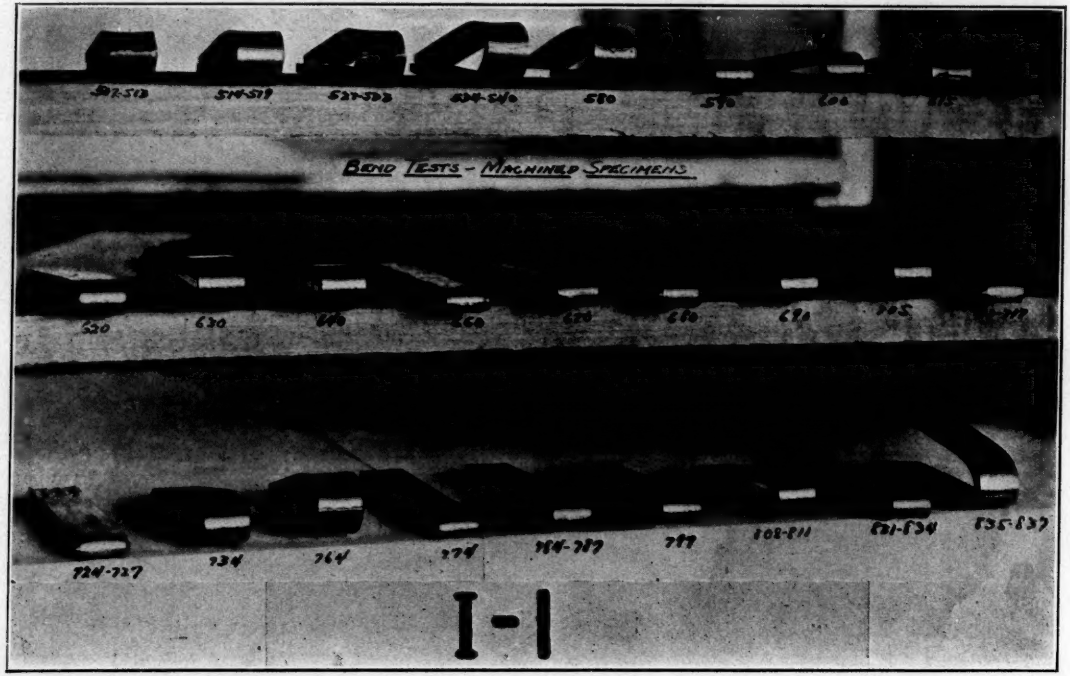
SHOWING POOR ALIGNMENT BETWEEN BLADE AND SHROUDING

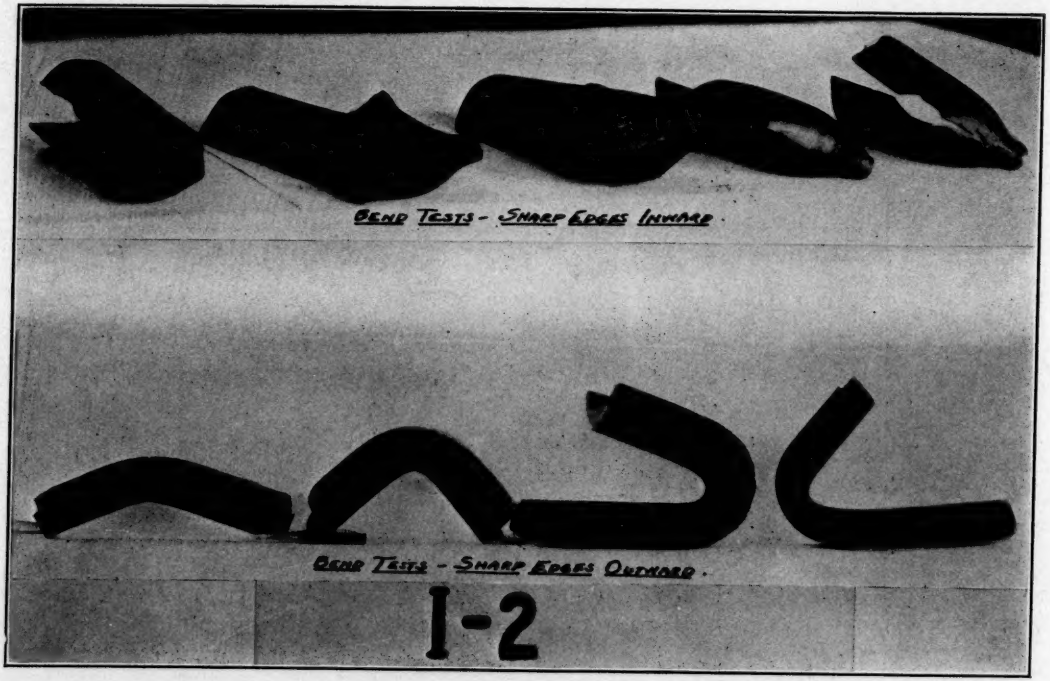
G-6



BLADES REPRESENTING EACH OF THE STAGES

H

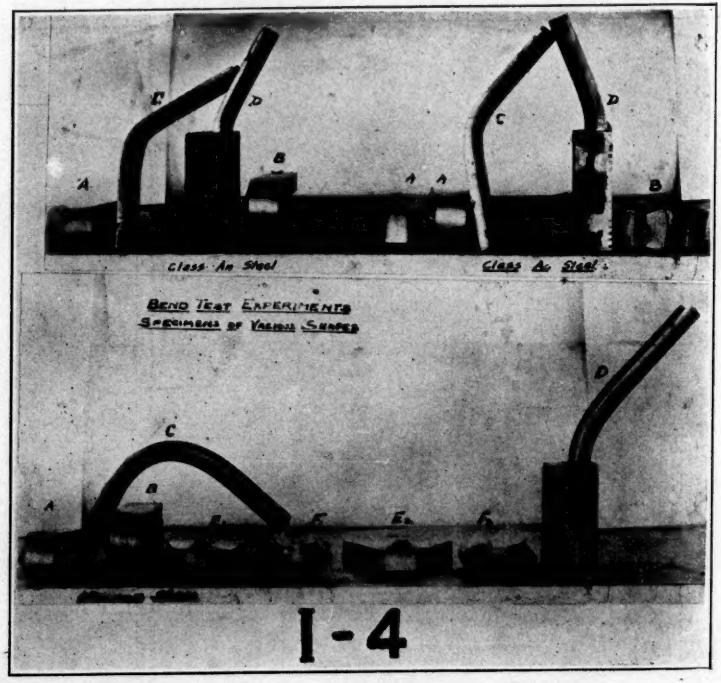

BEND TESTS - MACHINED SPECIMENS
I-1



BEND TESTS - SHARP EDGES INWARD.

BEND TESTS - SHARP EDGES OUTWARD.

I-2


A
B
C
D
A A
Class An Steel
Class Ao Steel
BEND TEST EXPERIMENTS
SPECIMENS OF VARIOUS SHAPES
A
B
C
D
E
E
E
I-4

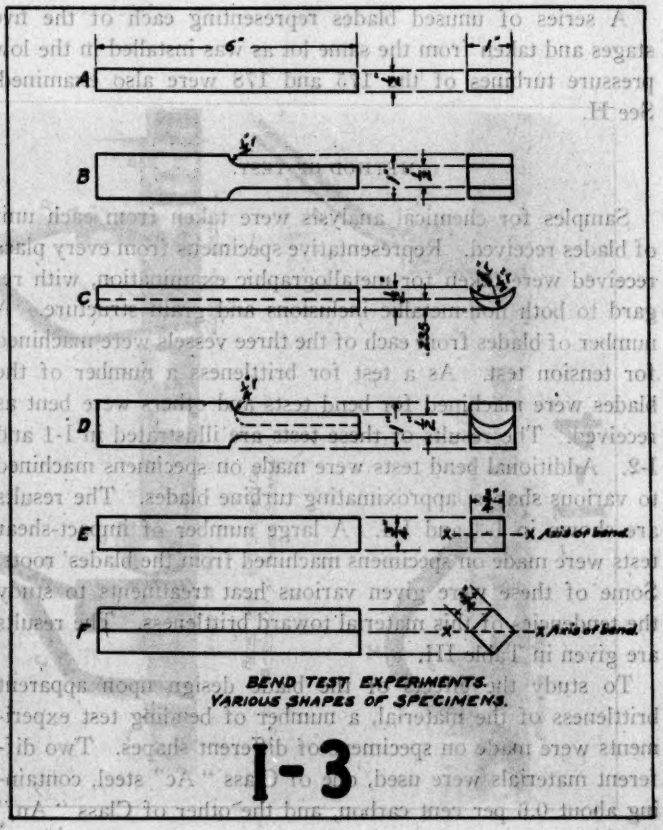
see G-3 and G-4, two blades which broke off while being installed in the 3d and 4th stages, see G-5, a new blade set in a section of shrouding, showing the lack of alignment between the two, see G-6.

A series of unused blades representing each of the five stages and taken from the same lot as was installed in the low pressure turbines of the 175 and 178 were also examined. See H.

METHOD OF TEST.

Samples for chemical analysis were taken from each unit of blades received. Representative specimens from every place received were taken for metallographic examination, with regard to both non-metallic inclusions and grain structure. A number of blades from each of the three vessels were machined for tension test. As a test for brittleness a number of the blades were machined for bend tests and others were bent as received. The results of these tests are illustrated in I-1 and I-2. Additional bend tests were made on specimens machined to various shapes, approximating turbine blades. The results are shown in I-3 and I-4. A large number of impact-shear tests were made on specimens machined from the blades' roots. Some of these were given various heat treatments to study the tendencies of this material toward brittleness. The results are given in Table III.

To study the effects of the blade design upon apparent brittleness of the material, a number of bending test experiments were made on specimens of different shapes. Two different materials were used, one of Class "Ac" steel, containing about 0.6 per cent carbon, and the other of Class "An," or 3½ per cent nickel steel. The shapes of the specimens are shown in I-3. These were arranged to show the effects of the "notch," and of sharp edges, on the tendency to fracture. The specimens, after bending are shown in I-4.



BEND TEST EXPERIMENTS.
VARIOUS SHAPES OF SPECIMENS.

I-3

RESULT OF CHEMICAL ANALYSIS.

The results of chemical analysis are shown in table I.

TABLE I.

CHEMICAL ANALYSIS.

	Blade No.	C	S	P	Mn	Si	Ni	Cr	Van
175									
Damaged Blades. See E.	19	.40	.043	.027	.70	.25	.42	1.15	.31
	67	.41	.045	.025	.70	.25	.42	1.15	.28
	67	.39	.045	.025	.69	.25	.41	1.15	.30
175 Spare blade	105	.36	.045	.025	.71	.23	3.28	.67	None
178	125	.27	.034	.007	.45	.17	3.51	.64	None
Damaged Blades. See F.	189	.27	.032	.005	.45	.18	3.28	.65	None
	176-177	.30	.038	.003	.39	.19	3.25	.64	None
280	331-335	.38	.048	.007	.61	.18	3.25	0.74	None
Damaged Blades. See G-1 & G-2	271-275	.38	.047	.005	.62	.20	3.25	0.74	None
	300-304	.39	.038	.003	.67	.17	3.20	0.74	None
	468-472	.38	.051	.004	.53	.25	3.26	0.74	None
280 1 Roots See G-4.	396-400	.36	.051	.004	.62	.23	3.20	0.74	None
280 blades from 3rd. & 4th stages broken while being installed. See G-5.	501-520	.43	.036	.011	.66	.29	.40	1.40	.06
	521-540	.43	.043	.015	.69	.25	.43	1.37	.04
280 damaged blades from 3rd, 4th & 5th stages. See G-3.	586-589	.38	.057	.009	.67	.20	3.24	.82	None
	655-659	.42	.039	.020	.70	.16	3.64	.67	.16
	706-709	.36	.048	.022	.74	.22	3.41	.19	None
Spare blades from all stages, from same lot as installed in 1m and 175 See H	711-750	.39	.043	.016	.73	.26	.39	1.35	None
	771-800	.27	.034	.006	.47	.14	.11	.63	.14
	801-814	.40	.046	.018	.69	.27	2.99	.78	.14

	Monel	Cu	Ni	Fe	Mn	Al	C	Si
	710-720	27.86	69.15	1.99	.68	1.69	.16	.09
	721-730	27.98	68.99	1.93	.84	1.96	.22	.18

RESULTS OF METALLOGRAPHIC EXAMINATION.

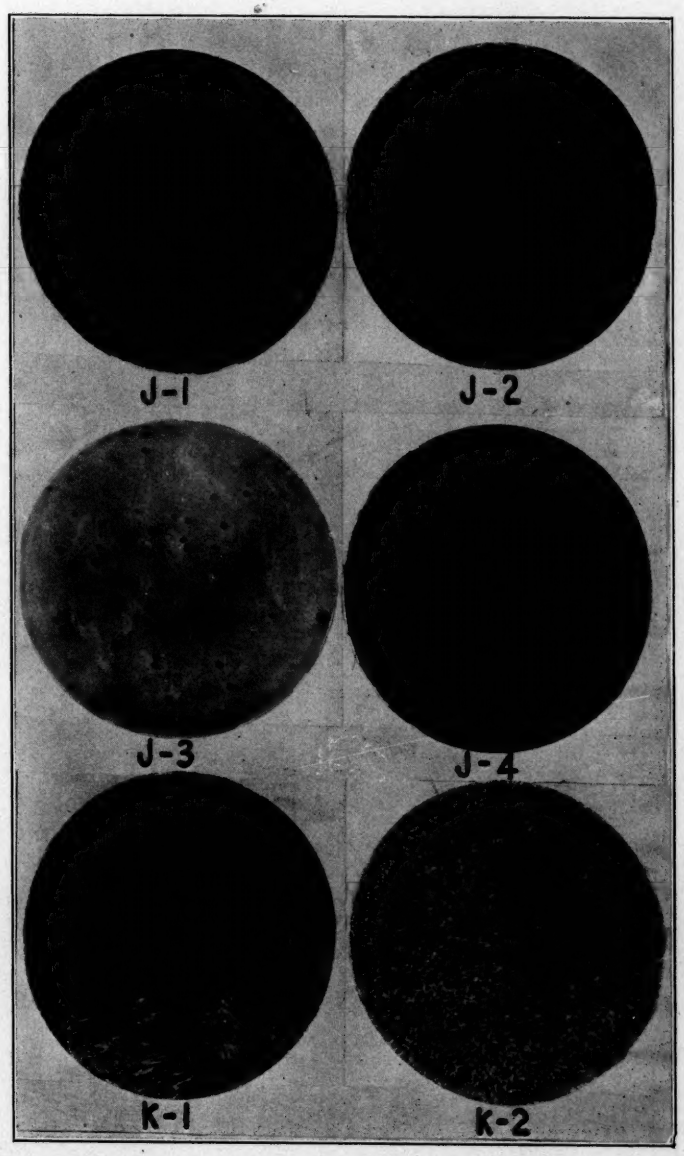
Photographs J-1 to J-4 illustrate typical structures of the blades from the 175 as shown in E. J-1 to J-3 show the structures of two damaged blades. Each was taken near a surface of fracture. The structures are uniform and the grain size varies from moderate to fine. J-3 shows the unetched surface of the same specimen shown on J-2. This specimen contains considerably more than an average quantity of non-metallic inclusions. This might be considered a limiting condition in these blades, since most of the others are somewhat cleaner. J-4 shows that the structure of the spare blade from the third stage is uniform and of small grain size, similar to that of the damaged blades.

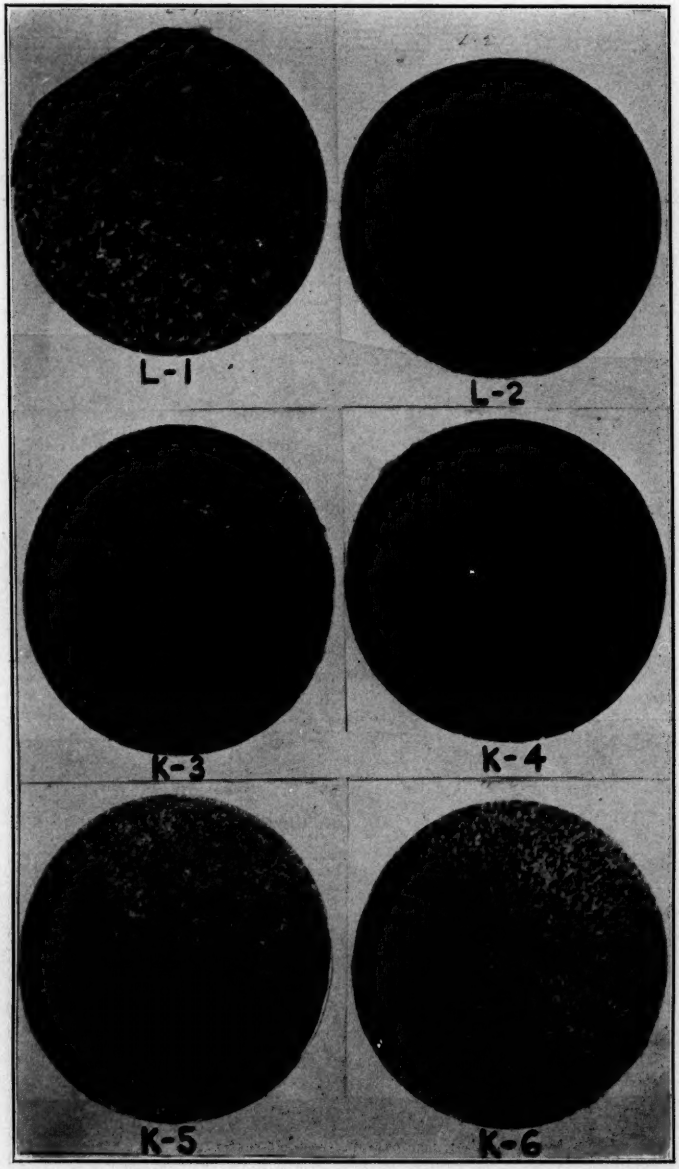
K-1 to K-6 illustrate typical structures of the blades from the 178, shown in F. K-1 shows the structure of a broken blade near the fracture. The photomicrograph shows a coarse triangular structure such as might result from quenching, possibly followed by tempering. K-2 shows the structure of a specimen taken from the same blade shown in K-1, after annealing. The grain size is small and the distribution of constituents is uniform. K-3 shows the structure of a specimen from the other end of the blade to be of small grain size. Slight vestiges of a banding of constituents remain in this region. K-4 shows the structure of one of the damaged blades to be sorbitic, indicating rapid cooling, possibly followed by tempering. K-5 and K-6 illustrate the variation from fine grain to moderate grain size and uniform structure typical of the other blades from this set.

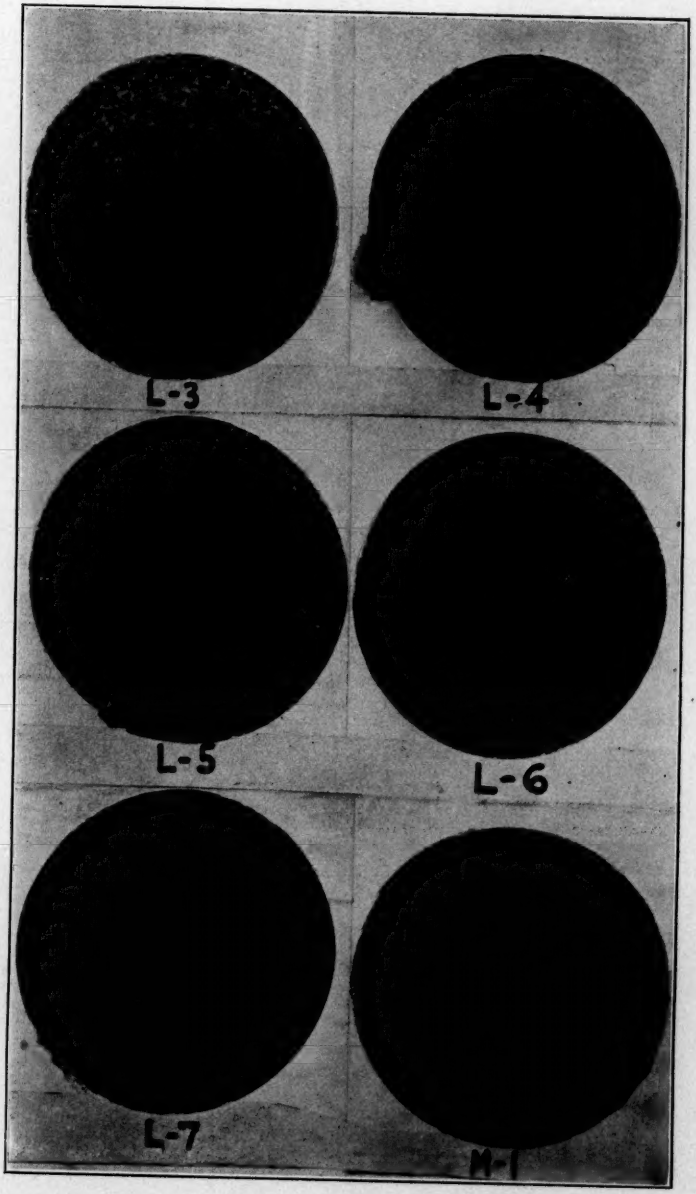
L-1 and L-3 to L-7 illustrate typical structures of the blades from the 280. L-2 shows the structure of a specimen of shrouding which structure is typical of all the shrouding examined. L-1 and L-3 show the structures of specimens from the damaged blades shown in G-1 and G-2. The structures throughout are uniform, the grain size varying from fine to moderate. L-4 shows the structure found throughout the damaged blades and blade roots, shown in G-3 and G-4, to be uniform and of moderate grain size. L-5 and L-6 show the structures at the base and at the tip of the third stage blade which broke while being installed. Near the break, the structure is sorbitic and of moderately large grain size. At the tip, as shown in L-6, the material has a very fine grain size. L-7 shows the structure near the break of the 4th stage blade which broke while being installed. The structure is decidedly non-uniform and rather coarse.

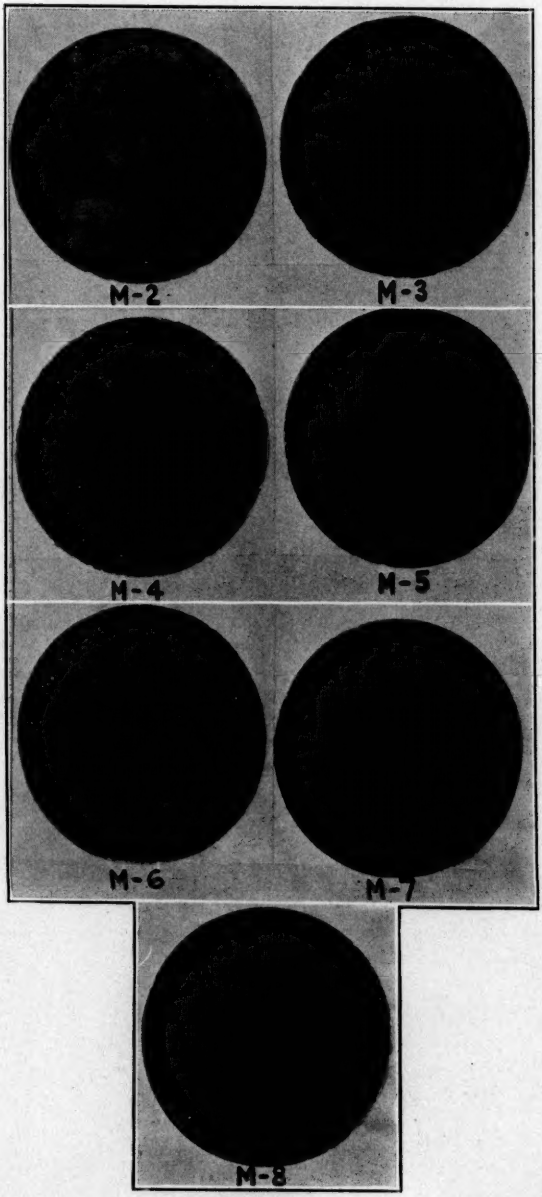
M-1 to M-8 show the structures of the set of blades representing each stage from the same lot as was installed on the 178 and 175; these blades are shown in H.

M-1 and M-2 show the structures of the two monel metal blades from the 1st and 2d stages, respectively. Each contains


J-1
J-2
J-3
J-4
K-1
K-2


L-1
L-2
K-3
K-4
K-5
K-6


L-3
L-4
L-5
L-6
L-7
M-1


M-2
M-3
M-4
M-5
M-6
M-7
M-8

a large quantity of non-metallic inclusions, particularly the second stage blade as shown in M-2. The grain size is small.

M-3 to M-5 show the structures of one of the third stage blades at the tip, base and root, respectively. At the base of the blade, as shown in M-4, the structure is decidedly non-uniform and coarse. A fine ferrite network marks out the coarse grain boundaries. It is notable that this structure is similar to that of the 4th stage blade shown in L-7, which blade broke while being installed. The structure, throughout the main blade body and the root, is uniform and of small grain size. See M-3 and M-5.

M-6 and M-7 show the structure of a blade from the fourth stage. At the root, as shown in M-6, the structure is uniform and of moderate grain size. At the tip, as shown in M-7, the structure is very coarse. Evidently this blade had been overheated at the tip.

M-8 shows the structure of the fifth stage blade at the root. Vestiges of banding of constituents remain. The grain size is small.

RESULTS OF TENSION TESTS.

The result of tension tests, made on specimens machined from the blade bodies, are given in Table II.

TABLE II.

Vessel.	Material.	Blade No.	Original Section, in.	Test Length, in.	TENSION TEST. Section at fracture.	Red. per cent.	Elong. per cent.	Yield Point, lb. per sq. in.	Tensile strength, lb. per sq. in.	Brinell hardness.
175	Chrome Nickel-Vana-dium	23-34	.486		.385					
			x.166	2	x.091	41.8	21.5	68,700	97,200	228
			.479		.385					
		70-76	x.099	1	x.066	50.7	28.0	60,800	94,700	228
	Chrome Nickel.	94-108	.476 x.124	2	.435x .110	22.0	12.5	94,500	142,900	310
178	do.	128-144	.440		.522x					
			x.151	2	.107	47.6	19.5	70,800	96,400	228
			.414		.335					
	do.	147-159	x.122	2	x.095	44.4	20.5	73,300	98,200	241
280	do.	306-318	.429		.335					
			x.077	1	x.060	39.1	24.0	87,900	110,900	269
	do.	351-356	.428		.335					
			x.105	1	x.084	31.8		89,600	145,600	350

RESULTS OF IMPACT TESTS.

The impact tests were made according to a method developed at the Experiment Station, published in the "Proceedings of the American Society for Testing Materials, Vol. XVIII, Part II, 1916." This method consists of shearing an unnicked specimen by means of a swinging pendulum. The residual energy in the pendulum is measured by the height to which it swings after breaking the specimen. The energy required to break the specimen is taken as an index of impact-shear toughness. The size of the specimen is ⅜ inch by ¼ inch, and the gripping vice is so arranged that one specimen can be moved along and sheared a number of times and the average results used.

Some specimens for impact were given various heat-treatments in order to determine the possibility of producing "temper brittleness" in these blades. The heat treatments are listed below:

	Treatment Letter.
1. *Annealed at 1500 degrees F.*	
Reheated to 968 degrees F., cooled in Furnace	A.
Reheated to 968 degrees F., cooled in Water	B.
Reheated to 1148 degrees F., cooled in Water	C.
Reheated to 1148 degrees F., cooled in Furnace	D.
2. *Quenched in oil from 1500 degrees F.*	
Reheated to 968 degrees F., cooled in Furnace	A′.
Reheated to 968 degrees F., cooled in Water	B′.
Reheated to 1148 degrees F., cooled in Water	C′.
Reheated to 1148 degrees F., cooled in Furnace	D′.
3. *Annealed at 1500 degrees F.*	E.

Table III gives the results obtained on material as received and on heat-treated material. In each case, the results obtained on a heat-treated specimen are given opposite the results obtained on an untreated specimen from the same blade.

TABLE III.

IMPACT SHEAR TESTS.

Vessel.	Material.	Specimen No.	Impact Values. Ft. lbs. per sq. in. Range	Average	Heat Treated. Specimen No.	Impact Values. Ft. lbs. per sq. in. Range	Average
As received.							
2nd Stage Broken Blades See G-4.	Chrome-Nickel Steel.	381	25.4-33.4:	29.7	385	1	25.7-29.2	29.4
		386	25.2-35.2:	30.2				
		406	25.5-34.5:	29.6				
		411	25.4-34.4:	29.7				
		676	25.4-33.4:	29.9	677	1	27.8-28.8	28.5
		945	25.6-34.6:	29.6	678	1	29.7-30.2	29.8
		961	27.9-30.9:	28.9	679	1	26.9-27.9	27.6
		680	27.4-27.9:	27.7	682	1	37.9-38.9	38.2
		681	26.8-29.8:	29.1	685	1	39.2-40.2	39.7
		668	28.5-28.8:	28.6	667	1	29.7-30.2	29.8
		670	26.0-27.0:	26.3	672	1	30.1-30.1	30.1
		685	27.9-28.9:	28.4	688	1	28.7-28.7	28.7
		681	25.1-26.1:	25.6	238	1	24.0-24.6	24.3
2nd Stage Blades. See G-4.	Damaged Blades.	891	25.4-25.4:	25.4				
	do.	681-2	24.3-24.3:	24.3				
	do.	201-3	29.7-30.2:	29.8	206-6	1	28.0-29.0	28.6
	"Burned" Blades.	214-6	30.6-30.6:	30.6	221-222	1	28.8-28.8	28.8
		710	30.8 ---	30.8				
	05-11 Van Steel.	714	34.7-35.7:	35.0				
Monel Blades See E-5.	------	721	33.8-33.8:	33.8				
		731	30.1-30.1:	30.1	745	1	34.7-35.2	34.9
3rd Stage See H.	Chrome-nickel Steel.	761	35.1-35.1:	35.1				
		762	32.9-35.4:	33.1				
	05-11 Van Steel.	771	37.4-37.4:	37.4				
4th Stage See H.	Van Steel.	781	37.9-38.4:	38.2	783	1	24.6-26.0	24.6
		791	37.9-38.4:	38.1	795	1	28.8-28.8	28.8
5th Stage See H.	Nickel Steel.	801	32.4-33.4:	32.9	806	1	30.6-31.6	31.1
	05-11 Van Steel.	811	32.4-33.4:	32.9				
Eccentric Blade See G-6.	------	859	25.8-54.3:	34.1				

RESULTS OF BEND TESTS.

The results of the bend tests on specimens machined from the blades to rectangular section, are shown in I-1. In most cases the specimens were bent flat through 180 degrees without signs of failure. Two specimens were taken from each of the two blades shown in G-5, which broke while being installed. Three of these failed when bent to about 180 degrees. One of the three specimens taken from the 3d stage of the 280 failed when bent through 180 degrees. A number of specimens from the 4th and 5th stages of the 280 showed only small surface cracks when bent through 180 degrees.

Of the entire lot of spare blades shown in H, only one specimen from the third stage failed and then only after bending through 180 degrees. Two specimens were taken from the eccentric blade shown in G-6 and one of them was given the heat treatment A′, see ante. The untreated specimen was bent flat on itself without cracking. The heat-treated specimen cracked when bent through about 170 degrees.

Since these tests did not indicate excessive inherent brittleness of the material, bend tests were made on sections of the blades as received, to determine the effect of the blade section shape on the amount of distortion that the specimen will undergo without fracture. A number of blades were bent with the sharp blade edge inward, and others were bent with the sharp edges outward. The results are shown in I-2. Those bent with the sharp edges inward were bent flat without cracking, excepting one which was given heat-treatment A′. This one cracked when bent to about 170 degrees. The four blades bent with sharp edge outward showed cracks in every case long before bending to 180 degrees. In one case the angle of bend was only about 45 degrees.

To show even more convincingly the inability of turbine blade sections to undergo bending without cracking, bend specimens of three different grades of material were machined to the shapes shown in I-3. These specimens were designed to

give a comparison of the action of bend specimens with the following kinds of test section:

(A) Rectangular cross section.
(B) Rectangular cross section with fillet at the danger section.
(C) Turbine blade section.
(D) Turbine blade section with fillet at danger section.

The materials used were machine steel, Class "Ac" steel, and Class "An" steel. The results are shown in I-4, which shows the angles of bend when cracks were first observed. As was expected, the specimen of rectangular section was bent flat without cracking; the other specimens cracked long before bending through 180 degrees, the order of decreasing angle of bend when cracks first appeared being B, C, D. Only a small degree of bending (about 20 to 25 degrees) was required to produce cracks in the D specimens, which were really close approximations of the actual turbine blades.

The specimens E and F in each case showed that the rectangular specimen bent on a diagonal axis could be bent to a greater angle than when bent on an axis parallel to its base.

DISCUSSION OF CHEMICAL ANALYSIS.

The chemical composition of the different sets of blades varied considerably. The specifications for the steel blades of the 178 and 175 originally called for chrome vanadium steel, but were later changed to require chrome-nickel steel. The result was that some of the blades were of chrome-vanadium and others of chrome-nickel.

The steel blades tested may be divided into two general classes, regarding chemical composition. The chrome-nickel steel blades contain about 3¼ per cent Ni. and ¾ per cent chromium and the chrome-nickel vanadium steel blades contain about 1¼ per cent Cr., 0.4 per cent Ni. and 0.1 to 0.3 per cent Van. A notable departure from this classification

occurs in the case of the blade from the 4th stage of the set of spare blades shown in H. This contains 0.11 per cent Ni., 0.63 per cent Cr., and 0.14 per cent Van.

The carbon content varies from 0.27 per cent to 0.41 per cent. The sulphur content in most cases is rather high, approaching, and in a few cases exceeding, the limit of .045 per cent usually allowed for high grade steel forgings. The phosphorus content varies, within normal limits.

The chemical composition of the monel metal blades conforms to specifications excepting an excess of aluminum.

The significance of these results in relation to the causes of failure will be discussed later.

DISCUSSION OF METALLOGRAPHIC EXAMINATION.

The examination of the unetched surfaces of these blades shows in most cases little more than an average quantity of non-metallic inclusions and these are well distributed throughout the metal.

The structures of blades from the 175 are all uniform, the grain size varying from moderate to fine.

Two of the blades from the 178 showed evidence of rapid cooling possibly followed by tempering. One of these showed a coarse triangular structure which is considered very undesirable. This structure was not found throughout the length of the blade, however, but only near the tip and undoubtedly marks segregation of the alloying elements. The structure of the remaining blades is normal.

Nearly all of the blades from the 280 showed a uniform structure of moderate grain size. The two blades from the 3d and 4th stages respectively which were broken while being installed both showed a coarse grain structure near the break, merging to a small grained structure at each end. The gradation from coarse to small-grained structure was quite uniform.

The monel metal blades from the 1st and 2nd stages of the set of blades taken from the same lot as used in the 178 and

175, each contained an excessive quantity of non-metallic inclusions. The grain structure was normal. One of the blades from the third stage of this set showed a very coarse non-uniform structure at the base of the blade, changing to small-grained and uniform at the ends. The structures of blades from 4th and 5th stages might be considered normal, excepting one blade which gave evidence of overheating at the tip.

DISCUSSION OF IMPACT—SHEAR AND BEND RESULTS.

The impact-shear test results serve to give evidence of the possibilities of inducting brittleness in this class of steel. It is well known that an excessive degree of brittleness may be induced in chrome-nickel forgings by tempering under certain conditions, after hardening. There seems to be a critical temperature range in the vicinity of 550 degrees C. (1022 degrees F.), which determines the effects of tempering treatments. After the initial quenching treatment, slow cooling from any temperature within the range 450 degrees C. to the transformation point temperature, may result in brittleness, the degree of brittleness increasing as the tempering temperature approaches the critical range at 550 degrees C. Quenching from 815 degrees C. (1500 degrees F.) followed by rapid cooling from above 550 degrees C. to the Ac point will leave the metal tough; if followed by rapid cooling from any temperature between 450 degrees C. to 550 degrees C. will result in brittleness. The above remarks are based on tests made on chrome-nickel steels of the class known as "high chromium-nickel," containing about 3½ per cent Ni. and 1½ per cent Cr. The results obtained, as shown in Table III, bear out this discussion.

Consider first those specimens which were initially quenched from 815 degrees C. (1500 degrees F.) and then given various tempering treatments. A comparison of impact- shear values of specimens from the same blades, before and after heat-treatment may be again summarized in Table IV.

TABLE IV.

EFFECTS OF HEAT TREATMENTS ON IMPACT-SHEAR TESTS.

Treatment after quenching from 815 degrees C.	Impact-Shear Values.	
	Before Treatment	After Treatment
Slowly cooled from 520 degrees C.	35.5	24.3
Slowly cooled from 620 degrees C.	38.4	28.7
Rapidly cooled from 620 degrees C.	38.5	29.8
Rapidly cooled from 620 degrees C.	36.5	30.1
Rapidly cooled from 520 degrees C.	38.2	24.6

The effects of simple annealing were variable, in some cases slightly increasing the impact-shear values, in other cases decreasing them slightly.

The bend tests on the blade material show that apparently in most cases the standard machined specimens could be bent through 180 degrees without signs of fracture. In some cases, failure after bending through approximately 180 degrees occurs. This shows that in general the material cannot be considered excessively brittle, although under certain conditions a slight tendency toward brittleness is indicated.

The bend tests on the blades as received, and the bend experiments on different shapes, throw light on the entire problem. It is a well known fact that in a stressed bar containing a sudden change in cross-section, the distribution of stress is not uniform in the section where the change occurs. Under some conditions, the maximum stress may amount to considerably more than the average stress in that section. The design of this type of turbine blade is such that a sudden change of section occurs between the root and the blade body. This section is the one of maximum bending moment and the maximum stress under bending would be considerably greater even than the theoretical stress. The shape of the blade section itself is very poorly suited to resisting bending loads without cracking. The sharp edges of the section are the points

farthest removed from the neutral axis and therefore subjected to the greatest stress when the blade is bent. The bend experiments show that such a section when bent with the sharp edges outward will crack much more readily than one of rectangular shape. Thus, in I-3 and I-4, specimens A, having a rectangular section, bent completely through 180 degrees without cracking, excepting the one of Class "Ac" steel, which just cracked at 180 degrees. A re-test of this specimen showed no crack. Specimens B with rectangular section, but bent at a sudden change of section also bent through 180 degrees, excepting the "Ac" steel specimen which broke at 90 degrees. The specimens C and D of turbine blade shape show cracks in every case. Those with the sudden change of section, crack much sooner than those of uniform section.

The weakness of the turbine blade section is also brought out in I-2. Turbine blade specimens bent with the sharp edges outward crack every time, in some cases after very slight bending. Those, bent with the sharp edges inward, in nearly every case bend completely through 180 degrees without signs of cracking, showing the inability of these sharp edges to undergo plastic deformation without cracking.

DISCUSSING PROBABLE CAUSES OF FAILURE.

The significance of the results obtained in these tests may now be considered in relation to the probable causes of the failures of these turbine blades. The cause of any failure of an engineering material may be classified as due to either faulty material, faulty design, or improper operation. These will be discussed separately.

The great variation in the chemical analysis of the blades indicates in many cases a wide departure from the A.S.T.M. specifications for chrome-nickel steels. The preponderance of chromium over nickel found in the blades containing over 1 per cent Cr. and about 0.5 per cent Ni., is an unusual combination. Bullens in "Steel and Its Heat Treatment" states

that "——if the chrome content greatly exceeds a certain proportion in respect to nickel, the steel will be more difficult to heat-treat successfully, the temperature limits are more narrow, and the possibility of poor results is greatly increased. The best ratio is probably about 2½ parts nickel to 1 part chrome." It is notable that the A.S.T.M. specifications for chrome-nickel steel of different classes, maintain approximately this ratio. However, the importance that may be attached to the variations of chemical analysis is minimized by the fact that failure occurred in the different sets apparently irrespective of chemical analysis.

It is well recognized that the forging of chrome-nickel steel must be carried on with great care to prevent the formation of fine surface cracks. Such cracks might easily be overlooked and in turbine blades would develop rapidly, due to the fatigue stresses caused by vibration of the blades in service.

The question of vibration in turbines, causing fatigue failures of blades, has been given considerable attention, and many turbine failures have been attributed solely to that cause. The results of investigations at the Experiment Station have shown definitely that under certain conditions, fatigue failures may be caused by stresses in the neighborhood of half the elastic limit of the metal as determined by static tests. With reference to this point, attention is invited to the conditions that existed on the 280 previous to stripping.

Mention might also be made of such possible contributory causes as fouling of blades due to expansion of the rotor wheels with overspeed, fouling due to improper turbine adjustment or poor alignment of blades, the presence of foreign objects or the presence of excessive quantities of water. Investigations of these various failures showed conclusively that such conditions did not exist.

In the final analysis, the above are considered only possible contributory causes of these failures. The heat treatment, bend and impact experiments show that although this material

in most cases is ductile, in some cases a slight degree of brittleness was observed in the metal. As ordinarily tested, using standard machined bend specimens, the material would not be classed as excessively brittle. When the subject of blade design in relation to bending tests is considered, however, the dangerous condition which may result following bending the blades is brought out. The bend experiments show that when using a specimen closely approaching the actual turbine blade in shape, even a slight degree of bending is sufficient to form, at the base of the blade, slight cracks, even though the material itself may be inherently quite ductile.

In this connection the information given in the reports of the Commanding Officer of the *Vestal* is very significant. These reports speak of the difficulties experienced in blading the turbines due to variations from the standard blade thickness and length, and due to lack of alignment between blades and shrouding. It was necessary to bend some of the blades considerably to fit them into the shrouding holes. This condition led to cracking some of the blades. In some cases the failure was complete as shown by the two blades in G-5. In other cases the cracks were undoubtedly very small, and easily overlooked. Stresses on the blade due to vibration in service would be concentrated at the base of such cracks, which would rapidly develop, and ultimately lead to failure, and stripping. In this connection it must be remembered that it is necessary to break only one blade, to cause stripping of an entire stage.

CONCLUSIONS.

Results of the chemical analysis of damaged blades from the 175 show these to be of chrome-nickel vanadium steel of the general composition Cr.-1.25, Ni.-0.40, Van.-0.20. The composition of the spare blade from the 175 indicates Cr.-0.70, Ni.-3¼, Van.-none. The blades from the 178 are of the same composition as the 175 spare blade. The composition of the blades from the 280 varies, including both of the above types.

One of the blades from the 4th stage of the 280 is of very unusual composition, containing Cr.-0.63, Ni.-0.11, Van.-0.14. The composition of the monel metal blades from the 1st and 2nd stages conforms to Navy Specifications, excepting a slight excess of Al.

The metallographic examination showed considerable variation of structures typical of this grade of metal. In most cases the structure is quite satisfactory. In a number of cases the structure gives evidence of rapid cooling possibly followed by annealing. In other cases segregation of constituents was shown. In a few cases wide variations of structure between different parts of the same blade indicated lack of suitable annealing. However, nothing about the microstructure was considered sufficiently unusual to justify attributing the failures entirely to faulty metal.

The results of various heat-treatment, impact-shear, and bend tests, show that while in most cases this material is quite ductile, in some cases a slight brittleness in the metal was observed. Under the worst conditions, however, the metal cannot be considered excessively brittle.

The results of the special bend experiments on specimens of various shapes when studied in connection with information given regarding the difficulties encountered in blading these turbines, indicate with little doubt, the cause of the whole trouble. The design of this type of turbine blade is such that it is very poorly fitted for undergoing plastic deformation when bent, without the formation of cracks at the junction of root and blade. While this is true even when the metal itself is very ductile, it is particularly true when there is a tendency to brittleness in the material due to faulty microstructure, or to other causes. In bending the blades to make them fit into the shrouding, a number of the blades cracked completely as stated in the reports of the Commanding Officer of the *Vestal* and as shown in G-5. Undoubtedly many other blades were only cracked slightly, and these cracks passed unnoticed. Under

the influence of service fatigue stresses, such cracks would rapidly develop, ultimately causing complete failure of the blade, and stripping of the entire stage.

While the conclusions arrived at in the preceding paragraphs were based wholly upon the investigation carried out at the Experiment Station, they are borne out by many other facts of which the investigator had, at first, no knowledge. These other facts, while it is considered inadvisable to publish them here, have to do with the history of the blade material, the forging of the blades, the history of the assembly of rotor wheels for the various classes, the condition of spares, the inspection of the material and the kind of labor employed.

The excellence of the report of the investigation which was carried on under the personal supervision of Mr. D. J. McAdam, Jr., cannot be too highly commented on.

While great care in turbine construction has always been an acknowledged necessity, attention is invited to the following:

(*a*) In specifying the raw material consideration must be given to effect that subsequent forging will have on the material.

(*b*) Heat treatment, at whatever stage or stages it should take place, must be carefully watched.

(*c*) A final heat treatment, that will insure uniformity should be given the blades.

(*d*) Each and every blade must be true to designed shape, otherwise, in attempting to install, deformation of blade will take place.

(*e*) Under no circumstances should a bent blade be installed nor should deformation of a blade, in order to make it fit, be attempted.

(*f*) The shroud band holes must be true with the tips of the blades and to insure this, after the blading is installed, a template should be made and from this the holes in the shroud band should be located.

(*g*) Every blade should be examined minutely, preferably with a glass, especially at the edges and around the root section, for cracks; if cracks are discernible, the blade should be scrapped.

(*h*) The blades in question can be strengthened against cracking, to some extent, by allowing a larger fillet between the junction of the blade and the root and widening the sharp edges of the blade at the approaches to the root. Such, however, while it may tend to counteract defective workmanship, will not eliminate the possibility of failure due to deformation.

(*i*) Blades of good material, improperly manufactured and mishandled during installation, are more likely to fail than blades of an inferior grade of material, properly manufactured and properly installed.

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NOTES.

THE FUTURE OF WARSHIPS.*

By Engineer Nabor Soliani.

The failure of the large pre-war battleships (Dreadnoughts and Superdreadnoughts), which are practically defenseless against a submarine offensive, should not lead to their complete abandonment. Where it is possible from the naval and the financial points of view to build large ships of the pre-war type, but improved by really effective protection against high-angle gunfire and against aeroplane bombs, torpedoes and mines, such large ships have not lost their efficiency nor their purpose (*raison d'être*). It would appear that both Japan and the United States hold this view. Great Britain, however, after having completed the battleship *Hood*, has in the meantime stopped building and has cancelled the order for sister ships to the *Hood*.

And, perhaps, with reason, since the *Hood*, with her 41,500 tons displacement and her cost of £6,000,000 (without counting the armor cost and so many other items), although a very fast ship, can hardly be reckoned as the large unit of the near future. As concerns our country, whose aim is simply to protect our coasts, the number of ships is quite as important as individual power. In view of these facts, I submitted a short paper to the Chief of Staff of the Royal Italian Navy last year, dealing (1) with a type of semi-submersible battle monitor, of relatively low speed, but capable of resisting effectively both the attack of torpedoes and mines, high-angle fire and the firing of aerial bombs; (2) with the scheme for a cruiser of small capacity, having no protection whether under or above the waterline, but powerfully armed (carrying four 381 mm. guns) and of extra high speed.

Since that time new data, due to the recent war, have come to hand, and it has appeared to me advisable to take up afresh the study of the units above referred to, and in particular of the monitors, which form more especially the subject of the present paper.

Monitors.—Particulars of the various types considered are given in the table herewith, the types designated as 2 B, 3 A and 3 B being reproduced in Figs. 1 to 9. The type 1 A was that proposed in the original paper referred to above.

The upper works disappear when the monitor is semi-immersed, and there remains exposed to above water attack only the deck, which is strongly protected in the types 1 A, 2 A, 2 B, and practically impenetrable. A sufficient angular stability for the safety of the ship is provided by the cambered shape of the deck and the relatively low position of the center of gravity of the ship in regard to the center of buoyancy, secured by the use of ballast.

* Abstract of a paper read before the Italian Society of Naval Architects and Marine Engineers at Genoa, December 4, 1920.

I wish to contrast this type of ship, slow, but practically invulnerable, or, to say the least, highly protected and of a relatively small bulk, with the battleship *Hood* of a higher speed, but larger, more costly and less protected. If it be reckoned that in these monitors the ballast (which costs nothing) forms about one-third of the displacement, it will immediately be seen that, with approximately the same expenditure, it is possible to compare one *Hood* of 32 knots and armed with eight 381 mm. guns, with three such ships of only 18 knots, armed with twelve guns of equal caliber as against eight, and better protected. This forms the main point for consideration in the selection of a type suitable for our Navy.

SEMI-SUBMERSIBILITY, STABILITY AND NAUTICAL QUALITIES.

(1) *Semi-submersibility* in itself has not much importance, especially in the case of a large unit with which it is not of easy attainment, while it decreases buoyancy; but is useful when the water round the hull is utilized as a form of protection.

SEMI-SUBMERSIBLE BATTLE MONITORS.
Principal Dimensions and Main Features of the various Types.

		1 A	2 A.	2 B.	3 A.	3 B.
Length	M.	130	130	130	150	150
Breadth	"	28	29	29	29	29
Depth	"	10	10	10	10	10
Draught, normal ..	"	6·50	6·80	6·80	9·10	9·08
Displacement	M. tons	18,500	21,500	22,000	31,000	31,000
Maximum draught ..	M.	10	10	10	11	11
Maximum displacement	M. tons	22,800	24,500	25,000	38,000	38,000
Engines—						
Type		Turbines.	Internal combustion.	Internal combustion.	Internal combustion.	Internal combustion.
Power	H.P.	40,000	24,000	24,000	24,000	24,000
Number of propellers ..		2	4	4	4	4
Speed at normal draught ..	Knots	30	18	18	18	18
Speed at maximum draught ..	Knots	19	17	17	16·5	16·5
Fixed solid ballast ..	M. tons	None	6,000	6,000	6,000	7,000
Water ballast	"	4,100	3,000	3,000	3,000	3,000
Under-water protection ..	"	Reinforced concrete.	Water	Water	Water	Water
Armor protection—						
Deck	Cm.	15	15	15	15	15
Belt	"	—	15	15	15	15
Armament—						
381 mm. guns		4	4	6	6	8
152		8	—	—	—	—
120		—	8	8	8	—
102		4	4	4	4	2
Reserve of buoyancy—						
About	M. tons	7,100	5,200	5,700	4,500	4,500
Immersed	"	3,000	2,200	2,200	1,500	900
Stability of forms—						
When afloat	M.	3·80	3·20	2·90	6·26	6·00
When immersed ..	"	4·20	2·90	2·80	—	—
Stability of weights—						
When afloat ..	M.	—	—	—	—	0·43
When immersed ..	"	—	—	—	—	0·75
Angle of stability—						
When afloat	Deg.	46	60	62	60	76
When immersed ..	"	42	45	48	360	360
Form of hull		Rectilinear.	Curvilinear.	Curvilinear.	Curvilinear.	Curvilinear.

The types 2 A, 2 B, 3 A and 3 B are of this character, the liquid subaqueous protection being on the Pugliese system, they differ from my original type 1 A, in which the under-water protection is of reinforced concrete on the lines advocated by Pecoraro Guidoni.

The 1 A type having no water ballast in the normal navigating trim has a maximum heeling angle of 46 degrees, which is reduced to 42 degrees by the water ballast in the double bottom. In a ship without water ballast the application of a belt of armor of 25 cm. and the abolition of the ballast pumps and piping, which are not then required, the center of gravity

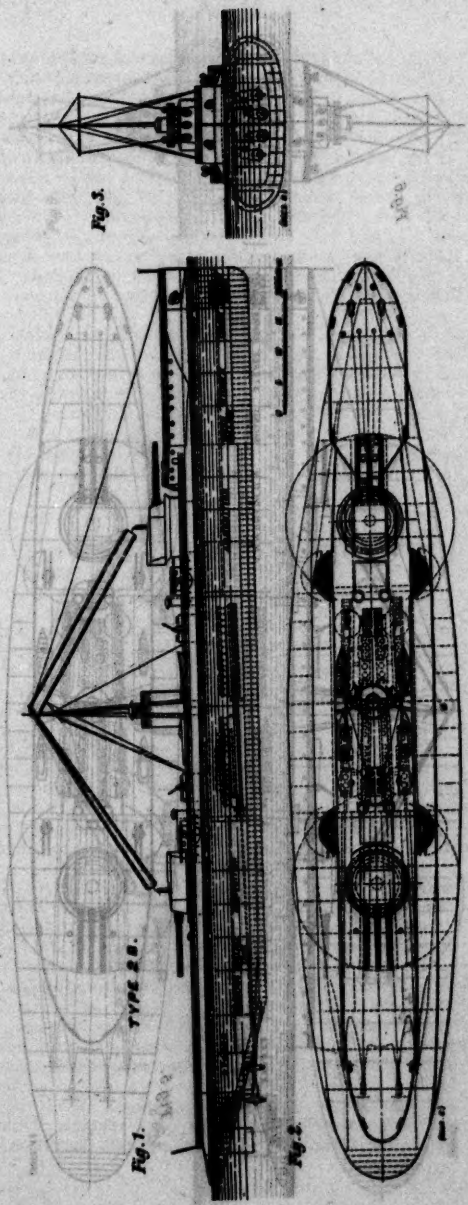
Fig. 3.
Fig. 1.
TYPE 28.
Fig. 2.

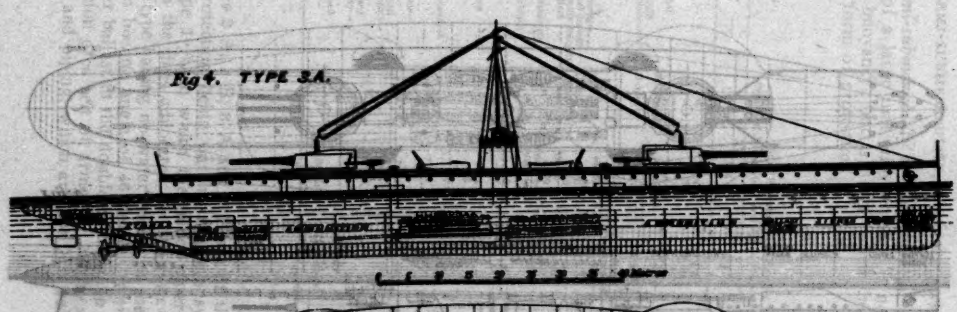

Fig 4. TYPE 3.A.

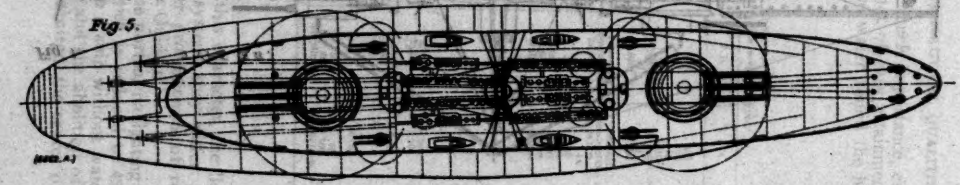

Fig 5.

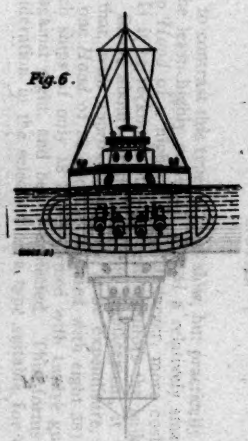

Fig 6.

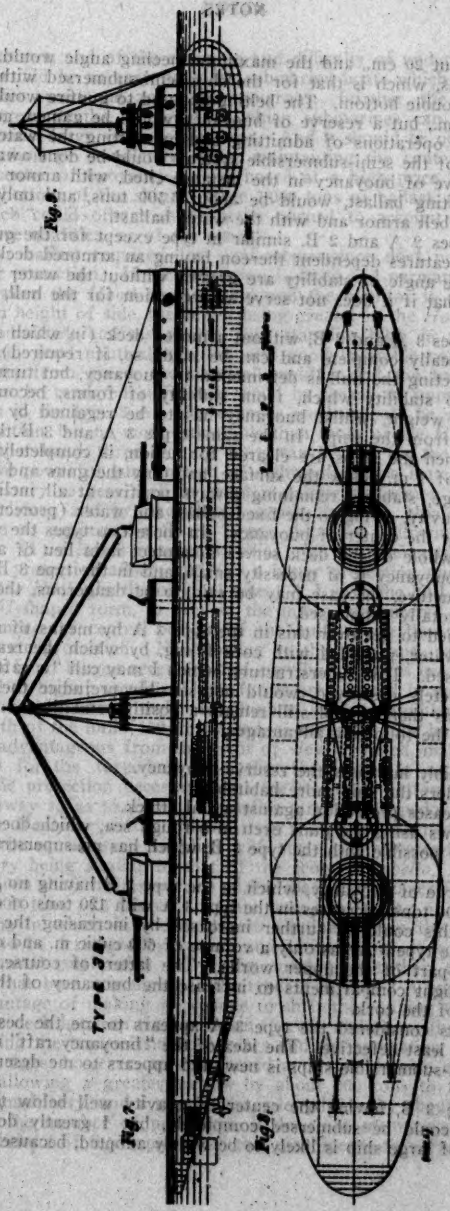
Fig 2.
Fig 3.

rises by about 20 cm., and the maximum heeling angle would be reduced to 42 degrees, which is that for the ship semi-submersed with water ballast in the double bottom. The belting exposed to gunfire would be higher by about 1 m., but a reserve of buoyancy would be gained, and the long and difficult operations of admitting and exhausting the water ballast, a weak point of the semi-submersible system, would be done away with.

The reserve of buoyancy in the instance cited, with armor belting and without shifting ballast, would be about 6,500 tons, and only 3,000 tons without the belt armor and with the water ballast.

In the types 2 A and 2 B, similar in type except for the gun arrangements and features dependent thereon having an armored deck, the buoyancy and the angle of stability are greater without the water ballast than with it, so that if it does not serve as protection for the hull, it might be eliminated.

In the types 3 A and 3 B, without armored deck (in which submersibility is practically complete and can be made so, if required), the water ballast protecting the hull is detrimental to buoyancy, but turns out to be favorable to stability which, from stability of forms, becomes positive stability of weight, whilst buoyancy has to be regained by discharging this ballast from the ship. In the same types 3 A and 3 B the deck, not armored, when the ships are cleared for action, is completely submerged at a depth of 1 m. below the surface, and only the guns and the conning tower emerge, stability remaining always positive at all inclinations, the center of gravity, owing to the fixed ballast and water (protective ballast), falling below the center of buoyancy. In these two types the water which covers the whole of the deck serves to protect it in lieu of armor. The reserve of buoyancy is of necessity small, and in the type 3 B, which has no superstructure, the case may be said to be dangerous, the ship being practically totally submersed.

I have tried to get over this in the type 3 A by means of upper-works above the water, provided with cork filling, by which the reserve is sensibly increased. This superstructure, which I may call "a raft," even if it were completely destroyed, would not sensibly prejudice the stability of the vessel, as there would still remain a positive stability of weights. It has besides the following advantages:—

1. It sensibly increases the reserve-buoyancy.
2. It renders the ship more habitable.
3. It increases protection against aerial attack.
4. It allows using the guns even in a rough sea, which does not appear to me to be possible with the type 3 B, which has no superstructure.

The reserve of buoyancy, which in the type 3 B having no upper works is hardly 900 tons, increases in the type 3 A with 120 tons of cork to 1,500 tons, and this could be further increased by increasing the cork filling, which in the type 3 A has only a volume of 600 cubic m. and occupies only the eighth part of the upper works. The latter, of course, are divided into watertight compartments to increase the buoyancy of the ship independently of the cork.

All points considered the type 3 A appears to me the best, or, if one wishes, the least defective. The idea of the "buoyancy raft" now referred to for semi-submersible ships is new, and appears to me deserving of consideration.

The type 3 B, having the center of gravity well below the center of buoyancy, could be submersed completely, but I greatly doubt whether this class of large ship is likely to be widely adopted, because of the small

buoyancy reserve, and of the slowness and difficulty of under-water manœuvers—it would be an easy prey for submarine boats which are smaller, have a higher speed and are more numerous. Further, the difficulty of diving to great depths, a condition which submarines can easily meet, militates against large submersible ships. And it should be noted that the ability to submerge completely, while maintaining the center of gravity below the center of buoyancy, is purchased at a high price by the addition in the bottom of the ship of quite 7,000 tons of ballast, an enormous weight which could otherwise be better turned to account in offensive and defensive qualities, or of the speed.

The water ballast required for semi-submergence does not serve for under-water protection. If the protection is fixed and permanent, the difference between the *Hood* type of ship and the monitor is reduced to a difference in height of side, the height being greater in the *Hood*, and this, it must be admitted, confers to the ship standing high in the water a greater speed, good nautical qualities and good habitable conditions.

Now, apart from speed, the nautical qualities and the habitability of monitors can be rendered sufficiently good by means of upper works, as will be seen in the type 3 A. These upper works would be vulnerable, it is true, in action, but no more vulnerable than those of the *Hood*.

On the other hand, three monitor units can be had for the cost of one *Hood*, twelve powerful guns instead of eight only and a better protection.

It is necessary to bear well in mind in taking a decision that, for an equal expenditure, and by sacrificing speed, there is obtained for the slower ships as against the faster larger ships the following important advantages: (1) a larger number of ships; (2) a higher artillery power; (3) a better protection afloat; and (4) a better protection under water.

Form of the Hull.—In the original type 1 A I gave the hull a rectilinear transverse, U-shaped form, to prevent the mines encountered by the stem exploding under the central bottom of the hull, where there is no reinforced concrete protection. Now, owing to the paravane, rectilinear U-shaped form is no longer necessary and curvilinear forms can be adopted, better suited to higher speeds. These forms are adopted in the types 2 A, 2 B, 3 A and 3 B, which make for higher speed, notwithstanding the greater length of the hull (150 m. instead of 130 m.). The hull is longer; this, whilst advantageous from the point of view of speed, makes a rather better target for the torpedoes, and therefore leads to an increase in weight of the protection necessary. At the stern the bottom part of the hull is cut away so as to present a smaller target to torpedoes.

Propelling Machinery.—The original type 1 A was designed to be propelled by turbine machinery supplied with steam from water-tube boilers, the machinery being similar to that of the scout *Mirabello*. It allows a power of 35,000 shaft horsepower to 45,000 shaft horsepower for a weight of about 1,000 tons. In the case we are now considering of a semi-submersible ship, in which it is desirable to eliminate from the deck structures likely to be destroyed by gunfire and aerial bombs, it would be best to adopt internal combustion propelling machinery rather than steam. This change has been introduced in the types 2 A, 2 B, 3 A and 3 B. This has the advantage of making it possible to shift the conning tower to the center of the deck between the two main turrets, and above the machinery thus improving the transmission of orders and the navigation of the ship. These advantages, however, are purchased at a considerable expense, for even when allowing a greater weight by about 200 tons to the internal combustion machinery, and a greater space lengthwise by about 10 m., and by doubling the number of propellers, it does not seem possible—in the present conditions of development of this machinery—to arrive at an in-

stallation exceeding 24,000 horsepower, in spite of adopting four twelve-cylinder engines on four shafts. Thus with internal combustion the power is reduced to about half, with a consequent reduction of speed from 20 knots to 18 knots. And the speed reduction would be still more marked if the greater length of the ship did not come in which, in the types 2 A, 2 B, 3 A and 3 B, is carried from 130 m. to 150 m., while the forms of the hull are also improved.

The relatively low figure of 24,000 horsepower is obtained by 48 cylinders of 500 horsepower each. On the other hand, in the type 1 A having steam turbines, the power of about 40,000 horsepower was obtained with only six turbines. This difference in complication is very marked, and reduces the danger of damages in favor of the turbines.

Captain de Feo has advocated the use of explosion motors, which would be lighter and take up less space, and faster running than internal combustion engines. I am sorry I am not able to share his views in this respect, for whilst the internal combustion engines have attained, not without difficulty, a power of 500 shaft horsepower per cylinder, it appears to me that the fast-running explosion motors are far from having reached this figure, there being, further, the difficulty of coupling the engines to the propeller shafts, and the latter are limited in number. Indirect coupling would certainly be possible by resorting to electric propulsion, but such a solution would be found more heavy and bulky than the internal combustion engines solution. It is not superfluous to add that both with internal combustion engines and explosion motors, the radius of action, with parity of fuel load, is at least two and a half times that which obtains in the turbine-propelled ship.

Above-water Protection.—As I have formerly stated, it is advisable that the above-water protection should be arranged on the outside, *i.e.*, in the deck and outside walls. It appears to me absurd to allow the projectiles to penetrate to the inside. The decks and the partitions should only act as protection against shell splinters. In the types 2 A and 2 B all the protection above water is concentrated, as in the original type 1 A, on the deck and belt at the water-line, the maximum of protective armor thickness being 15 cm.

In the matter of the horizontal armor, the curved armored deck which, in pre-war ships, was usually level with the lower deck, slightly above the water-line, in the *Hood*, is round the sides below the water-line, having its central portion raised to the height of the battery deck, thus giving the ship better protection if the external side armor, between passage and battery, was pierced. This innovation, I may say, was actually suggested by the Ansaldo, Sestri Ponente Yard in 1912.

Under-water Protection.—In the type 1 A under-water protection is obtained by means of walls of reinforced concrete on the Pecoraro Guidoni system behind an outside air chamber, the object of which is to deaden the violence of explosions against the concrete wall. This air chamber is a weak point of the system, since in case of a tearing effect by the shock of a torpedo the ship takes a heavy list.

For this reason, in the types 2 A, 3 A, 2 B and 3 B I have adopted a liquid under-water protection (a system derived from the one devised by Engineer Pugliese), having the advantage of not occasioning any sensible list of the ship even when struck by torpedoes. This advantage still remains, however, to be proved. The strong timber protection which I proposed during the war for the under-water protection of ships, would be more certain in action, but has the disadvantage of the impossibility of lightening the ship (by discharging the protective liquid mass), and with consequent increase in speed and buoyancy-reserve.

The *Hood* is protected under water by the so-called "bulge" filled with drums. By filling with cork the interstices between the drums, the effective flooding of the bulge should a torpedo strike its outside wall might be kept down to quite a small amount, and this would explain the good effect which the bulge has had during the war. This protection would be both lighter than that of reinforced concrete, and that of the Pugliese type which, taking the water and the internal protection, weighs approximately 3,000 tons, a weight which could be reduced by using a bulge of equal volume to about 1,000 tons. By using this kind of protection in our types there would be no need for the water ballast, and there would follow a saving in weight of approximately 2,000 tons, which could be utilized partly in belt armor and partly in increasing the buoyancy-reserve. It could also be utilized for decreasing the displacement and increasing the speed.

By applying such a modification to the type 3 A, in which the reserve buoyancy can be increased independently of the water ballast (by increasing the volume of the cork filling in the upper works), the displacement of the ship in normal navigating and fighting trim would decrease from 24,600 tons to 22,600 tons, the positions of the center of buoyancy and of the lower center of gravity remaining the same, so that the conditions of stability, otherwise satisfactory, would also remain practically unaltered.

As Captain de Feo has well said, the outside under-water protection will have to be intimately combined with the inside protection by means of minute subdivision, both vertically by transverse watertight bulkheads and horizontally by watertight decks, so as to minimize flooding both above and below the water-line, and so reduce to a minimum the consequent loss of buoyancy and stability. It is well to avoid longitudinal subdivisions which, by limiting flooding to one side only of a ship, results in a marked heeling. In the types dealt with in the present paper such minute subdivisions are not indicated, the schemes as put forward being simply in elementary form.

Armament.—In all the types I have excluded torpedo tubes, which appear to me to be inefficacious on board a large ship. The armament is limited to guns. The type 1 A has 381 mm., 152 mm. and 102 mm. guns; in those of 2 A, 2 B and 3 A, following the ideas of Captain de Feo, I have replaced the 152 mm. guns by others of 120 mm., which can be used against submarines, torpedo boats and aeroplanes. There are also four 120 mm. anti-aeroplane guns, which could be done away with.

In the type 3 B in the matter of small calibers there are but two 102 mm. guns, owing to lack of space. This is insufficient, and for this reason the type 3 A is to be preferred. In the types 1 A and 2 A there are only four 381 mm. guns in two double-gun turrets. On the other hand, in the types 2 B, 3 A and 3 B the main armament consists of six 381 mm. guns in two triple gun turrets. This change from double to triple gun turrets appears advisable, since whilst it avoids having recourse to superimposed turrets, it allows the simultaneous firing of three guns per turret, which facilitates the regulation of the firing. In the type 2 B the addition of two guns makes the angle of stability rather small. This is not the case in the types 3 A and 3 B, where it remains large, this being a point in favor of the latter types, and especially of 3 A, for the reasons already stated.

In the types 3 A and 3 B the main armament is limited to six 381 mm. guns in two triple gun turrets, instead of six guns still in triple turrets but of a larger caliber, or of eight (381 mm. or larger) guns in two quadruple turrets which would allow greater precision and a greater intensity of firing. This has been done to keep the center of gravity low, so as to

secure an angle of stability sufficient for the safety of the ship when immersed and stability when entirely submerged.

Speed.—When dealing with the propelling machinery I stated that, with the type 1 A having steam turbines of about 40,000 horsepower, a speed of about 20 knots could be reckoned upon, whilst in those of 2 A, 2 B, 3 A and 3 B, having internal combustion engines of only 24,000 horsepower, the speed was only about 18 knots, notwithstanding that the hull in these latter types was, in length and shape, more favorable to speed.

If in the latter turbines were fitted instead of internal combustion engines, the speed would be about 21 knots instead of only 18 knots. This point is against internal combustion engines in their present state of development. One must hope that the future progress in internal combustion engines will lead to the fitting on board ship of higher power engines comparable to turbine power.

Rudders.—Notwithstanding the greater resistance offered, it is advisable to provide two rudders instead of one, or one main rudder in the center and two smaller side rudders, to ensure navigating the ship if one rudder be damaged.

Conning Tower.—In all the types the conning tower is only outlined; it would have to be studied from the points of view of navigating the ship and directing gunfire.

Mast.—I have reckoned on one mast only, passing through the center of the conning tower, the latter acting as a protection. The mast carries the wireless telegraph system, and can be lowered to prevent the ship from being seen by submarines at short distances.

Ventilation.—A large shaft concentric with the conning tower supplies air inside the ship.

Note.—I am afraid that the submarines carrying heavy artillery, such as the "M" class of the British Navy, having a speed of 17 knots on the surface and armed with a 305 mm. gun, can compete with the battle monitors above referred to.

This gun has no training gear, and traversing is carried out by keeping the stern of the submarine in line with the target by steering. It would appear, however, that this method of traversing has given good results.

Not much is known of these submarines. It is known, however, that their displacement does not exceed 2,000 tons. It would be possible to argue that for the cost of building one monitor of about 20,000 tons, there could be constructed at least six submarines of the same speed, which could probably carry out all the war operations open to the battle monitors, at least in our seas.

Extra High-Speed Battle Cruiser.—As a complement to the monitors, which are powerful ships both in offense and defense, but slow, I proposed battle cruisers, powerful in offense and having extra high speed, but without any protection either above or under water. These were 9,000-ton ships, having a speed of 35 knots, armed with four 381 mm. guns in two unarmored revolving turrets, and with eight 152 mm. guns. This type of ship could be improved by the addition of the bulge and of a light armor protection, as in the British *Courageous.* On these lines a 12,500-ton ship could be designed in which the 152 mm. guns at the sides are replaced by twelve 120 mm. guns along the longitudinal axis of the ship, there being at the sides twelve torpedo-launching tubes. Owing to the rapidity and precision of present-day gunfire, it is to be feared that such ships of high speeds and well armed, but without above-water protection would quickly be sunk by fire from battleships. Speed and artillery power are good qualities for a ship, but above all things the ship must remain afloat. Captain de Feo believes that for scouting it is preferable to have

recourse to smaller ships of the torpedo boat class, less powerful in offense but very fast, such as our scouts *Mirabello* and *Sparviero*.

General Remarks.—The present study of battle monitors and light cruisers of high speed and powerful armament is only of speculative value. In the present political, financial and economical conditions of our country it would, I believe, be inopportune to follow an extensive naval program. It is permissible, however, to study new ships. But for the present our Navy may limit herself to improving the under-water protection of the existing ships, to paying attention to the lighter craft, scouts, destroyers and others, to following closely, above all, navigation under water and in the air, both of which are developing and are destined, better than battleships and cruisers, to provide the country with the required defense.—"Engineering," January 7, 1921.

OUR FIRST ELECTRIC BATTLESHIP.

Although the Admiralty continue to preserve absolute secrecy respecting the new battleships, various statements as to their supposed characteristics are appearing in the technical press. The latest report is that one of the four ships will be equipped with the turbo-electric drive which has been adopted for all the big American warships now under construction. This system has not yet been tried in the British Navy, nor have our naval engineers shown any noticeable enthusiasm for it, but the fact that it has given complete satisfaction in America proves it to possess certain marked advantages over the geared turbine arrangement. Exhaustive trials carried out with the *New Mexico*, the first big warship to have electrical transmission, show an important saving in fuel consumption and superior maneuvering powers as compared with other ships. With the adoption of the electric drive special astern turbines can be dispensed with, for while the main turbines continue to revolve in one direction only, the electric motors which they actuate are reversible.

Electric drive is often referred to as very complicated; in reality it is very simple. Besides doing away with astern turbines, it does away with mechanical gears by permitting the turbines to rotate at their normally high speed, at which they develop their maximum efficiency, and the propellers to turn at the comparatively low speed which gives them their maximum driving efficiency. Hitherto the British Navy has almost always been first in engineering enterprise, and but for the exigencies of war it might have maintained that lead. Even as it is, our Navy holds the world's record in more than one branch of engineering, such as the application of the geared turbine to ships of unexampled steaming power and speeds. If we are now about to adopt the electric drive it is because the internal-combustion engine is not yet sufficiently developed to warrant its embodiment in great ships of high speed, but that the future belongs to this type of engine is not seriously questioned by anyone who ranks as an authority.—"The Naval and Military Record," June 22, 1921.

MECHANICAL REDUCTION GEARS ON WARSHIPS AND MERCHANT SHIPS.

By John H. Macalpine.

I have studied two excellent papers which appeared in "Engineering" in the spring of 1920. These are "Experience and Practice in Mechanical Reduction Gears in Warships" (April 9, p. 474), by Engineer-Commander H. B. Tostevin, D.S.O., R.N. (read before the Institution of Naval Architects in March), and your editorial, "Reduction Gearing on Steamships," May 7, 1920, page 599.* Might I ask room for the results of a careful analysis of these as they seem, in a remarkable degree, to justify the anticipations which gave rise to the invention of the floating frame and I trust the analysis will be found to throw light on the present situation which, at least in regard to double reduction gears, is not a very happy one.

Commander Tostevin (Vol. CIX, page 477; T.I.N.A. Vol. LXII, page 133)† states the "empirical rule," $p = K \sqrt{D}$, which has very largely been adopted in Britain, where $p =$ the tooth pressure per inch run, K a constant, and D the diameter of the pinion. This same rule was also deduced in a theoretical investigation given in "Engineering" (Vol. CII, page 119) which seemed to me not to take full account of the essential facts. In a letter (Vol. CII, page 527) I gave reasons which seemed to indicate that the rule $p = K\sqrt{D}$ was much nearer the truth, and it was with great interest that I found in your editorial (Vol. CIX, pages 599 and 601) that further researches based on entirely different considerations go far to confirm this view—called by you "the American view"; though, unfortunately some of the engineers in the States seem to be far from clear on the subject.

That the "$\sqrt{D}$ rule," as we may for brevity call it, does not express a theoretical truth follows at once from the fact that if applied to similar gears the stresses in the metal of the smaller ones will be higher and will rise without limit as D diminishes toward zero. With the "D rule" these stresses will be constant. I have discussed this question somewhat fully in former papers and will not take your valuable space to rediscuss it at length here. (See T.I.E. & S., Vol. LXI, page 380, *et seq.*; and Vol. CI,

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* The two papers mentioned herein were reprinted in the JOURNAL OF THE AMERICAN SOCIETY OF NAVAL ENGINEERS, vol. xxxii, pages 388 and 563.

† It would add greatly to the length of this paper to quote all the passages referred to but what is written will be much more fully intelligible if these references are consulted. In such references where no publication is mentioned, "Engineering" is to be understood. The following contractions are also used:—

T.I.E. & S. = Transactions of the Institution of Engineers and Shipbuilders in Scotland.

T.I.N.A. = Transactions of the Institution of Naval Architects.

T.S.M.E. = Transactions of the Society of Naval Architects and Marine Engineers (American).

J.A.S.N.E. = JOURNAL OF THE AMERICAN SOCIETY OF NAVAL ENGINEERS.

page 416.) As the "D rule" gives the same value of the power constant,* for all diameters of pinion, and as the validity of this law has always been assumed in designing floating frame gears, there is now a large body of evidence for the truth of the deduction. The "$\sqrt{D}$ rule," if properly termed "empirical," must have been founded on experience with rigid gears. The details of that experience I do not know, but as the rule has been generally adopted in Britain it probably is an expression of the experience of a number of makers—possibly of many. The apparent discrepancy indicated by the use of two rules puzzled me for a time, but as fully stated in my Glasgow paper referred to above, the reason must be that the larger gears are, in one important respect, not similar to the smaller gears; that is, their bedplates or casings will be relatively thinner and more elastic. The rigid gear depends almost entirely on the rigidity of its casing while the floating frame gear does not to nearly the same extent and, hence, it appears perfectly natural that while for large gears the use of the floating frame allows the value of the power constant to be kept up, with rigid gears it must be diminished. This will be found to give a consistent explanation of very much in the two papers under discussion.

A rigid gear is a redundant structure and in every redundant structure the danger of unequal distribution of stress makes it imperative that the designed stresses be kept much below those which could be employed safely were the distribution definite. If we supported a gear wheel with its axis horizontal and brought up the pinion to it, without placing it in bearings, the involute teeth engaging with a uniform pressure all along the helices, we would, as is well known, find that the axes of gear and pinion were parallel whatever the distance of centers. If both axes are in the same horizontal plane, it would be impossible to rotate the pinion axis in the vertical plane to an amount that the finest gauging could detect, without wholly upsetting the condition of uniform tooth pressure. But the relation of these axes is also determined by the bearings in which the gear and pinion have to run; and this, obviously, is a perfectly independent condition. It is only by painstaking care that they can be made approximately consistent. It was to remove this obvious and great redundancy that the floating frame was devised towards the end of 1905, and the first complete design made in the following year. It was the design and wholly successful trials of this gear in 1909 which gave the needed impulse to the recent great development of the geared turbine.

Long before these trials I very carefully calculated the elasticity of the teeth, due both to flexure and shear. Such a calculation is only a rough approximation as the usual formulas do not apply to a beam so very short in proportion to the dimensions of its cross section; and they do not follow the stresses into the body of the pinion and gear. The result is probably an

* As I will frequently have to use the power constant and as its expression may not yet be generally known I will define it—

$$\text{Power constant} = C = \frac{1{,}000\,P}{D^2R},$$

where P = horse-power transmitted.
D = diameter of pinion in inches.
R = R.P.M. of pinion.
(See Vol. CI, page 416.)
It applies exactly to similar gears and, very approximately, over a considerable range of ratio of helix length to pinion diameter above and below that ratio which gives the highest safe power. (T.I.E. & S., Vol. LXI, page 847). I concluded that the best ratio of helix length to pinion diameter is in the neighborhood of 2 for a three-bearing pinion. (Vol. CI, page 457).

under-estimate, but not greatly so. The circumferential pitch was 1¼ inch and the helical angle 30 degrees. The load supposed in the calculations on one pair of teeth in contact was 1,000 pounds per inch run. The sum of the yields of the pinion and gear teeth were as follows:—

	Yield. Unit, 1/10,000 inch.
Point of gear tooth engaging flank of pinion tooth.....	5.60
Teeth engaging at pitch line.....	2.48
Point of pinion tooth engaging flank of gear tooth.....	5.13

I have, consequently, always maintained that an error of alignment of 1/1,000 inch in a bearing is important. If so, every casing, except perhaps those of very small gears, must be looked on as sensibly elastic structures. It is a frequent belief, and Commander Tostevin seems to share it (Vol. CIX, page 478; T.I.N.A., Vol. LXII, page 134), that clearance in the bearings removes the difficulty; but Professor Osborne Reynold's investigation of the theory of lubrication lends no countenance to this. (Vol. CII, page 527 and footnote. The figure .0007 in the footnote should obviously be .00007.) I will revert more fully to this important question.

Considering the rigidity of the teeth, the redundant structure, and the elasticity of the casing, it is not surprising that Commander Tostevin gives such a prominent place to questions of alignment and distribution of tooth pressure, by frequent references all through his paper, and Mr. Walker's sympathetic commendation (Vol. CIX, page 472; T.I.N.A. Vol. LXII, page 141) of the treatment of this subject is good evidence of much vexatious experience.

Fig. 1.

Commander Tostevin believes that the casings do not suffer distortion under working conditions (Vol. CIX, page 478; T.I.N.A. Vol. LXII, page 134), though the low power constants of the gears given in his Table I and other facts which he details find simple and consistent explanation in the opposite belief. While proper design can give a maximum of rigidity for a given weight of metal it cannot make iron and steel inelastic materials nor can any calculation forestall subsequent severe concentration of tooth pressure in service (Vol. CIX, page 478; T.I.N.A. Vol. LXII, page 134). He then refers to ships where relative motion with misalignment took place between the turbines and gears and states: "In later designs this movement is not possible, as the after-ends of the turbines are now supported on stiff extensions of the gear case, the whole installation forming a rigid unit." (Vol. CIX, page 478; T.I.N.A. Vol. LXII, page 134.) The construction is perfectly proper, but to say that this long unit is now even approximately rigid and movement impossible seems to me a grave mistake.

The complete structure is much more elastic than are the two parts—the turbine and gear—each within itself. However heavily built, its elasticity could be readily proved by supporting it in the middle and bolting it down at the two ends. That this is not an exaggerated test and that it has a counterpart in reality is proved by the first paragraph of the "Extract from Admiralty Specifications" (Vol. CIX, page 480; T.I.N.A. Vol. LXII, page 139), which provides that the accurate alignment of the gearing will not only be tested in the shop but afterward when erected on board ship. The first two paragraphs bear conclusive testimony to the well-known delicacy of aligning, and clearly reflect a large amount of troublesome experience. The case is even stronger than I have so far stated; for it is important to note that the specified double test, in shop and ship, refers to the gearing alone, thereby recognizing the very important degree of elasticity which its casing possesses, to which Commander Tostevin's paper otherwise bears so much evidence.

In the combined structure there are four (or five) turbine and pinion bearings, which should be brought into line well within an error of 1/1,000 inch; and the same must be done for each pinion meshing with the large gear. This reminds one in a very exaggerated degree of the difficulty of the laborer, with which all gear builders will sympathize, who could always get two posts in line but never three. An adjustment so delicate is surely subject to displacement by the slightest accident and may be upset at any moment. This cannot be guarded against by repeated tests—it constantly exposes the gear to danger. Indeed, the limits being so fine as the rigidity of the teeth indicates, there is no reason to believe that uniform distribution of tooth pressure under working conditions can be assured even initially. Red lead, or other markings with a sensible thickness of film, will not do this, and it cannot be told whether it has been attained by subsequent examination of the teeth (Vol. CIX, page 479; T.I.N.A. Vol. LXII, page 136) as there are wide limits of pressure within which the teeth will take a fine polish. Indeed, if there are fluctuations of alignment a beautiful uniform polish might result though at times the teeth were not bearing along their whole length

While the tieing together strongly of the turbine and gear casings is obviously a correct and very necessary thing to do, surely it is not good practice to depend on it so entirely for good alignment if this can be escaped without detriment. If it can be escaped, as I believe, with great advantage this dependence is less commendable still.

There is a very interesting passage (Vol. CIX, page 478; T.I.N.A. Vol. LXII, page 134) referring to teeth on which the load had not been distributed over the whole length. The conclusion reached is that the helical angles of the pinion and gear were not the same. That this was due to "a slight slow slip of the pinion in the chuck" is hardly credible as the slip would have to be extremely uniform to leave a presentable surface. This difference of angle, I am informed, has also sometimes occurred in the experience of the Westinghouse Company. It could not fail to be detected in the shop from the markings of the teeth when first run together. It is never of large amount and I could not imagine a maker of these fine gears so unintelligent as to leave it uncorrected. Commander Tostevin's description of the result is not quite full enough to say definitely what happened, but if the helical angle was properly corrected, there are still two possible explanations of the observed results. I am only putting forward suppositions which may be examined by those who have access to all the facts:—

(1) If the hard bearing occurred at both ends of both the right and left-hand helices it is precisely what would occur in a rigid gear due to a change of alignment, if the loose coupling between the turbine spindle and pinion were acting properly.

(2) If the hard bearing showed itself at the outer end of one or both helices it might be due to misalignment accompanied by derangement of the loose coupling, through wear roughening the pins or other sliding parts and making them offer too great resistance to end motion of the pinion. The loose couplings now in general use are a menace to any gear.

Perhaps it is not realized by all how high the maximum pressure will become for a slight change of alignment. I have before me the report of a rigid gear examined after it had run a perfectly satisfactory trial. At one end of one helix the teeth were not bearing at all for fully 25 per cent of the length of the helix. In Fig. 1, ab is the face of the helix and an exactly even distribution of pressure all along this helix may be represented by the dotted line cd. But the bearing was only from e to b, three-quarters of ab. The pressure must have risen from zero at e to a maximum at f, increasing approximately as represented by the straight line ef. For the same speed and power obviously the area of the rectangle ad must be equal to that of the triangle ebf. Therefore,

$$ab \times ac = \frac{1}{2}\, eb \times bf.$$

Hence, denoting the uniform and maximum ununiform intensity of pressure per inch by p and P respectively, we have

$$\frac{P}{p} = \frac{bf}{ac} = \frac{2ab}{eb} = \frac{8}{3} = 2{\cdot}67.$$

This or an even greater margin must be allowed for in the constants used in designing a rigid gear. It is a condition which does not and cannot occur in a floating-frame gear. The only reason for inventing the floating frame was to avoid such a detrimental and otherwise unavoidable distribution. I have explained the simple dynamics involved in several papers* and need not repeat here. I have also shown that if a pinion in a floating frame goes slightly out of line from any cause, such as the wear of the bearings, it automatically does so by a rotation about an axis parallel to the line of action of the teeth (Vol. CI, page 479) "Errors of Alignment," or T.I.E. & S. (Vol. LXI, page 33) and that such a rotation, until it has reached a far greater value than would occur in practice, would not sensibly affect the good distribution of tooth pressure. A curve for the large experimental gear is given of opening of contacts at the outer ends of each helix due to such a rotation, supposing the teeth absolutely rigid. It shows that a horizontal error of ⅛ inch in 9 feet, 4½ inches, or over 6 minutes of arc, is negligible so far as the good action of the teeth is concerned. Further, in such a gear, if there is no horizontal error there can be no vertical error.

This valuable automatic adjustment has no counterpart in the rigid gear; though Mr. R. N. Walker and, I believe, some other builders seem to suppose, since there is "always a certain amount of natural flexibility in all such structures" (T.I.E. & S. Vol. LXI, page 365), that self aligning takes place to some extent in rigid gears; not recognizing that this flexibility is responsible for far the greater part of the difficulties of alignment so impressively shown by the two papers under discussion. Keeping align-

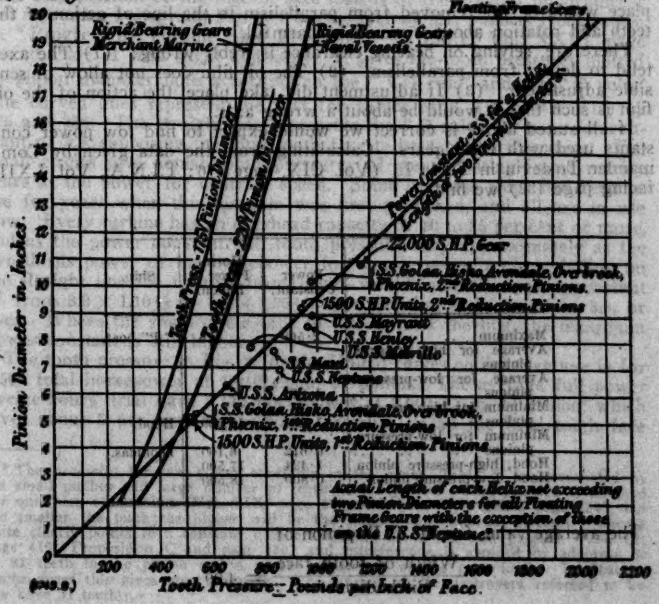
* Or see the editorial in "Engineering," (Vol. LXXXVIII, page 377), written before the first gear was tried; especially Fig. 6 and accompanying text, page 378.

ment is the principal function of the casing. The only merit of the above quotation is that it fully admits the sensible elasticity of the structure.

Hence we see that, compared with the great and perpetually recurring difficulty of misalignment in rigid gears, the question can hardly be said to exist for floating-frame gears. All that is done is to push the floating frame toward the large gear till collars outside the helices of the pinion come against block gauges held against similar collars on the gear. The I beam of the floating frame is then bolted down and the operation is complete. The accuracy of the adjustment can readily be ascertained at any time by gauging between these collars; and, as explained above, a small but sensible error is of no importance. The floating frame must, obviously, be sufficiently stiff to resist sensible flexure by either the tangential or radial components of tooth stress, at full power.

Commander Tostevin states (Vol. CIX, page 478; T.I.N.A., Vol. LXII, page 134) that "the line of centers through the turbine and pinion should be *free to remain parallel* with the axis of the wheel, and the clearances in all the bearings should permit of this, otherwise misalignment will take place." The last clause seems clearly to involve belief in important elasticity of the bedplate. But the whole quotation is practically a statement that the parallel position is exceedingly stable, whereas it is slightly unstable; that is, the action of the teeth alone would tend to increase any error of horizontal alignment which existed and this tendency would increase with the error. Hence, clearance of the bearings beyond what is

Fig. 2.


Floating Frame Gears
Rigid Bearing Gears Merchant Marine
Rigid Bearing Gears Naval Vessels
Tooth Pressure - 750 Pinion Diameter
Tooth Pressure - 200 Pinion Diameter
Power Constant = 3.5 for a Helix Angle of 30° Pinion Diameter
22,000 S.H.P. Gear
U.S.S. Golaa, Hako, Avondale, Overbrook, Phoenix, 2nd Reduction Pinions
15000 S.H.P. Units, 2nd Reduction Pinions
U.S.S. Maumee
U.S.S. Hendry
U.S.S. Marcello
U.S.S. Mount
U.S.S. Neptune
U.S.S. Arizona
U.S.S. Golaa, Hako, Avondale, Overbrook, Phoenix, 1st Reduction Pinions
15000 S.H.P. Units, 1st Reduction Pinions
Axial Length of each Helix not exceeding two Pinion Diameters for all Floating Frame Gears with the exception of those on the U.S.S. Neptune.
Pinion Diameter in Inches.
Tooth Pressure - Pounds per Inch of Face.
(218.8.)

best for lubrication is not advisable and the pinion will not seek the parallel position. To definitely supply any lack of stability struts are fitted abutting on the floating frame.

In the letter I referred to above (Vol. CII, page 527) I have pointed out that Professor Osborne Reynolds' mathematical investigation of Mr. Beauchamp Tower's experiments opposes the belief that there can be valuable self-adjustment of the position of an oil-borne journal in a bearing. But it at once follows from his investigation that even if the adjustment were sufficient to consider it would not serve the purpose desired. If the line from the center of the bearing and passing through the position of minimum thickness of the film oil coincided with the direction of the resultant pressure, as in (600, Fig. 2)—or, what is very nearly the same, was parallel to the line of action of the teeth—and if the parallel position of the axes were stable, the automatic adjustment, *if very slight*, might be exact; that is, the rotation of the pinion axis would be about an axis parallel to the line of action of the teeth (as it always is when a pinion is held in a floating frame) if during such rotation the minimum thickness of the oil film did not change. If the adjustment were larger, so that the movement of the journal center were a sensible fraction of its radius, the total rotation, constrained as it is by the curved surface of the bearing, would obviously be about another axis, varying in direction as the adjustment increased. But the position of minimum thickness of oil film is always at a considerable angular distance from the point just indicated, not less than 40 degrees, Professor Reynolds shows, and in some cases much more. Thus the axis of rotation about which adjustment would take place would be far removed from parallelism to the line of action of the teeth and rotation about it would be harmful.

Therefore, relying on bearing clearance is trebly wrong: (1) The axes tend to depart from parallelism. (2) The oil film does not allow of sensible adjustment. (3) If adjustment did take place, the action of the oil film is such that it would be about a wrong axis.

If all stated above is correct we would expect to find low power constants used with rigid gears. Calculating from the data given by Commander Tostevin in Table I. (Vol. CIX, page 476; T.I.N.A., Vol. LXII, facing page 132) we find:—

—	Power Constant.	Horse-Power of Pinion.	Ship.
Maximum	2·568	875	"P" boat.
Average for high-pressure pinions	2·07		
Average for low-pressure pinions	1·87		
Minimum for high-pressure pinions	1·424	17,500	Hood.
Minimum for low-pressure pinions	0·812	6,100	Leonidas.
Hood, high-pressure pinion	1·424	17,500	
Hood, low-pressure pinion	0·809	18,500	

The average value for the H.P. pinion of

$$\frac{\text{Width of tooth face}}{\text{Pitch diameter}} = 4.09$$

and most of them are quite near this value, so that making comparison with floating-frame gears, in which the ratio is almost always very near 4 (since the tooth face is twice the helix length) the use of the power constant cannot be objected to. For the L.P. pinions this ratio is smaller, as in Table I these are nearly always larger in diameter than the H.P.*

The power constants of floating-frame gears are usually much larger than those just given. In the very early gears, or where tooth pressures have been specified, or where a pattern was used for a smaller power than the original design, comparatively low power constants may be found; but even before 1916 power constants of 4 had been found to be quite safe (Vol. CI, page 492, Table; or see T.I.E. & S., Vol. LXI, page 349 Table.) The United States collier *Neptune* has a pinion diameter of 7 inches and the breadth of face is 5.15 times this, which I believe is considerably above the best ratio. Nevertheless the average power constant on the 12-hour full power trial, November 17, 1915, was 5.22, at 14.28 knots average speed, the contract speed being 14 knots. During the war she had hard service. At last report the gear teeth were in excellent condition and show little sign of wear.

(In tests made in the Westinghouse shops in Essington recently there are strong indications that even 5 is not the limiting safe power constant, and I have long urged them to build a gear with ample bearings so that they would run cool at a power constant of 8 or 10. I am very sanguine that experience indicates these values might be safely reached with floating-frame gears.)

As this question of the highest safe load is of the greatest importance I will reproduce a diagram, Fig. 2, from a paper by Mr. Francis Hodgkinson on "Progress of Turbine Ship Propulsion" (T.I.M.E. Vol. XXVI, page 59 and Plate 31 with slight addition). It gives the tooth pressures plotted on pinion diameter both according to the "$\sqrt{D}$ rule" and the "D rule." The curved lines represent the first for values of K (in $p = K\sqrt{D}$) of 175 and 280. The straight line represents the "D rule" for a power constant of 3.3, supposing the total tooth face to be 4 pinion diameters. The small circles give actual tooth pressures of some floating-frame marine gears at the power for contract speed. Some of these ships had been in use for years when this diagram was first published, and all are in use now. Every turbine has an overhead capacity of 10 to 25 per cent or more, and as the power constant and tooth pressure vary approximately as the two-thirds power of the horsepower for marine gears, a circle falling on the straight line for floating-frame gears would indicate a power constant of from $3.3 \times 1.10^{2}/_{3}$ to $3.3 \times 1.25^{2}/_{3}$, or over, that is from 3.5 to 3.8, or over. Where the small circle falls to the right of the line, the maximum power constant is still higher.

The tooth pressure in Fig. 2 for the United States collier *Neptune* is for 6,500 total horsepower at 1,910 r.p.m. of pinion. The average full power twelve-hours' trial gave 7,175 horsepower at 2,008 r.p.m. of pinion, which gives about 5 per cent higher tooth pressure. Had the total tooth face

* The necessity for low power constants in the gears, Table I, is accentuated by the small pitches and large number of teeth in the pinion. This practice is adopted for quietness of running (Vol. CIX, page 476; T.I.N.A., Vol. LXII, page 133), but the smaller the pitch the higher will be the surface and internal stresses. Theory quite clearly points to a constant number of teeth being the best practice (Vol. CI, page 416: Proposition C and page 520) and interference is avoided by adopting 30 or 31 teeth in the pinion and a proper addendum of the gear tooth. In floating-frame gears this gives quiet running. The pinions of the destroyers referred to below have 31 teeth.

been made 4 diameters of pinion instead of 5.15—which reduction would, I believe, have made a better and safer gear—there would have been a still further increase of tooth pressure in the ratio $\frac{5.15}{4}$, or 29 per cent. This illustrates the danger of using only tooth pressure in designing as, after a certain length of tooth face is reached any increase, while it will reduce mean tooth pressure will also reduce the factor of safety.

In Commander Tostevin's Table I, page 476 we have—

Maximum value of K = 226.

Minimum value of K = 152.

Mean value of K = 197.

A just comparison can, therefore, be readily deduced from Fig. 2.

If we have two similar reduction gears transmitting the same power at the same speed of pinion, it can readily be shown (Vol. CI, page 520) that the weight is inversely proportional to the power constant. The power constants, given above, for H.M.S. *Hood* are 1.424 for H.P. pinion and .809 for L.P. pinion. Hence, allowing for the weight of the floating frames and required changes in the casing, and without exceeding the power constants now in common use, it is within the truth to state that a floating-frame gear to transmit the same power as each of the *Hood's* could safely be built on half the weight. Whether the reduced pinion centers could have been adopted in the *Hood* depends on the clearance between the turbines; but, if the total reduction of centers could not be made, the length of the tooth face could have been shortened, thus saving much weight. If the turbine speed has been determined by a desire not to exceed a certain pitch line speed, it can now be increased (for the same propeller speed) with an additional saving of weight, for, though the large gear diameter would then be kept up to give the greater ratio of reduction, the saving of weight in the two turbines would, no doubt, far more than compensate this increased weight of the large gear.

There seems no reason to doubt that the relative weights of direct driven and all-geared sets (Vol. CIX, page 479; T.I.N.A., Vol. LXII, page 138) could thus have been considerably modified in favor of the latter.

The turbine and gear then being connected by an elastic driving shaft in addition to a loose coupling, there would not only be almost complete independence of the elasticity of the gear casing, but also of the more or less elastic junction of the turbines and gears.

Commander Tostevin writes (Vol. CIX, page 478; T.I.N.A. Vol. LXII, page 134) of the disadvantages of the floating frame shown by experience over a number of years but, unfortunately, does not state what he has in mind or I would gladly have discussed them. I know of none. On the contrary the floating frame has performed far beyond my most sanguine expectations, allowing the safe use of much higher power constants than I anticipated. It annuls completely delicacy of alignment—that great bugbear of rigid gears—and was devised because this great difficulty was clearly foreseen. It is more firmly fixed in the favor of the Westinghouse engineers than ever; and the responsible authorities in the Navies of the United States and Japan, who also have first hand experience, do not seem to share the opinion expressed by Commander Tostevin. It will, probably before this is printed, be in 36 United States destroyers and is now in 30 of these which have performed perfectly; and one of these, the *Satterlee*, holds the official speed record in its class, 38.25 knots, with a tooth pressure of 1,175 pounds per inch on a pinion pitch diameter of 10.227 inches—a much higher pressure than for the *Hood* whether compared by the "D rule" or "D $\sqrt{\text{rule}}$," and every allowance made for a rather short tooth

face (26 inches, as the gears had to be shortened). The tooth pressure of the *Hood* seems to be considered high (Vol. CIX, page 599). The Japanese have, built and building, a large horsepower of gears of various sizes, from comparatively small to great in one gear. That the floating frame functions as intended is proved by the slight pitting which frequently occurs in both land and marine gears. This, which no doubt shows local excessive pressure, is, in these gears, nearly always distributed all along the tooth face;* and wear, where it has taken place measureably, is also evenly distributed.

There have been some troubles, especially in the hurry of the war orders. Of these Commander Tostevin seems to have heard some report, but, had he known the details, he would have recognized that in no single instance were they attributable to the floating frame. For instance—

(1) For reasons which seemed sufficient to some of the Westinghouse engineers, a long addendum tooth was adopted in the pinion. This was done by making one less tooth in the pinion than would have given the usual addenda. Consequently, the arc of contact was displaced; the

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* Several fanciful theories have been put forward regarding the cause of pitting. It seems to me to be quite sufficiently accounted for by the slight imperfections of machining which undoubtedly occur, probably combined with lack of perfect homogeneity in the steel and somewhat loose structure in places. It is greatest at the pitch line as the teeth are stiffest when the pitch lines are in contact (See Vol. CIX, page 599 and also the figures given at the beginning of this discussion). The fact that the pitting stops soon puts aside the theory that invokes the presence of water in the oil—still more that which imagines explosions of entrained air and the oil! Failure of the oil film due to the pure rolling at the pitch line does not seem a very likely contributing cause as pitting sometimes occurs far from the pitch line; also I have a record before me of a 4½-inch pinion at 150 r.p.m. carrying a load of 1,400 pounds per inch of tooth face. When examined after six months the teeth were in perfect condition. If the oil film did not fail in this slow running pinion it is not likely it does so under much lighter load and higher speed.

It has been noticed by the Westinghouse engineers that the pitting is frequently greater on the gear than on the pinion. They believe this to be due to a slight flow of the metal. The sliding on the pinion when driving is from the pitch line in both directions—toward the tooth base and the point—hence the fin which is so often found at the outer edge of the pinion tooth. But on the driven gear tooth the sliding is toward the pitch line from both directions and flow will build up a slight ridge. This of itself is probably not enough to explain greater pitting on the gear as the surface pressures always remain equal at all points of contact; though, as we pass inward, the intensity of compression will fall more slowly in the ridged tooth. But the flow probably loosens the structure of the more or less crystaline metal and makes flaking of the built-up ridge easier. Also, it may be that the larger mass of the rim has not been so thoroughly worked and consequently has a looser structure than the pinion.

It should be noted that another, and I believe the principal, cause of the ridge is the zero sliding at the pitch line. The sliding at all other parts of the tooth face gives the abrasion shown by polishing. This abrasion will combine with increased elasticity to lighten the contact pressure taken by the sliding parts of the tooth surfaces. Where a ridge appears on the pinion, which, I think, is sometimes the case, it must be due to this cause. However produced, a ridge will accentuate the effect of elasticity in causing greater pitting at the pitch line.

In the 6,000-horsepower experimental gear, pitting appeared early in the trials and caused some anxiety. I had lead strips hammered into some of the teeth, the whole length of the helix, which gave a clear record of the pitting, and then directed that a narrow strip in the neighborhood of the pitch line be scraped. So far as could be judged this completely stopped the action, but the trials were not continued long enough to make sure.

In the first (and I think second) gear which went out, a strip at the pitch line was planed by a small tool made specially for the purpose. This gear after running almost night and day for over eight years broke a small portion of a tooth in the pinion which was, quite unnecessarily, replaced by a new pinion. The teeth otherwise were in perfect condition without a trace of pitting. I may also mention that the teeth of gears supplied to the San Diego Railway Company about ten years ago were found recently to be in excellent condition.

earlier part of the arc of contact, as usually designed, was cut off and the latter part extended. When the teeth are approaching the line of centers the interstices are diminishing and the oil squirted in very thoroughly lubricates the surfaces. But there is very little space for oil to pass the line of centers and after this line is passed the interstices are increasing. The combined effect of the limited oil supply, the pockets more than sufficient to contain it, and the high centrifugal force, is that the teeth are worse and worse lubricated as the end of the arc of contact is approached. Consequently, teeth so designed very readily cut. In SS. *Agawam*, the first of the war orders to go out, the teeth cut on several trial trips, after which a careful investigation was made, by trials of gears in the shops, before the cause was definitely found. Also, an examination of previous records showed that all the gears which had cut, unless where it was known that lubrication had failed, had the long addendum pinion tooth. In all cases where cutting had occurred due to failure of lubrication, the teeth smoothed and polished again when supply of oil was re-established. These investigations led to the remaking of a very large number of pinions with an extra tooth at large cost of both money and time and, naturally, great annoyance. When these pinions were installed this difficulty vanished.

(2) When the first of 34 destroyers, United States *Clemson*, was tried the gears were found to be excessively noisy; so much so that the Navy Department refused to accept the ship till they were made quiet. This led to a second tedious and costly investigation in the shops before the cause was definitely found. The application of the remedy, which in no detail altered the floating-frame design, has resulted in the *Clemson* and all her sister ships having gone through their trials in an eminently satisfactory manner and the gears have been quiet. As noted above, one of them holds the official speed record in her class. From (Vol. CIX, page 477) it appears that the foregoing difficulty also was experienced in Britain.

(3) Also as in Britain, there have been some cases of teeth breaking. Always, where examined it was found to be due to defective material. In no case had the design to be changed. For instance, during her return from France on her maiden voyage some teeth broke out of the starboard high-speed pinion of the *Sudbury* and she had to proceed to port using the low pressure turbine only. Examination showed defective material. These pinions are similar, as to material and design, to 25 other pinions now in successful operation.*

It may be interesting to note that in floating-frame gears it has not been found necessary to use nickel-steel in the pinions as is specified by the Admiralty (Vol. CIX, page 480; T.I.N.A., Vol. LXII, page 139), nor need the dangers of more complex alloys be incurred (Vol. CIX, page 479; T.I.N.A., Vol. LXII, page 136). The fact that good carbon steel answers all purposes, notwithstanding high power constants, is a further indication that all stresses are well distributed.

(4) There have been some failures of lubrication and there always will be. Against serious accident due to this the floating frame is in some instances a great protection. Thus, in one of the destroyers a bearing of the main gear burned out and the bearing went down 60/1000 inch. This had no effect on the teeth as the floating frame, elastically mounted, allowed the pinion to accommodate itself to the changed position of the gear axis. In a rigid gear point contact would have been produced.

* For a list of the troubles experienced with marine turbines and floating-frame gears, see "Progress in Marine Turbine Propulsion," by Mr. Francis Hodgkinson (T.S.M.E. Vol. XXVI, page 65, *et seq.*).

(3) About 1913 there was installed at the works of the British Westinghouse Company (now the Metropolitan-Vickers Electrical Company, Limited), Trafford Park, Manchester, England, a floating-frame gear. It unfortunately was of a type in which the pinion bearings are supported on hydraulic pistons—a type to which I all along objected as it is complex, delicate, and costly. It has been abandoned years ago and the original I beam construction reverted to. However, many of these gears acted perfectly, among others those of the *Neptune*, which gave the high power constant of 5.22. But the *Manchester* gear seemed to get completely out of adjustment and was exceedingly unsatisfactory. Mr. K. Baumann, Chief Mechanical Engineer of these works, assured me this gear had only brought a bad reputation in Britain, which I can well understand. The Metropolitan-Vickers Company have now installed a floating-frame gear of the I beam type, which has none of the delicacy or complexity of the other.

Before leaving Commander Tostevin's paper I wish to express my appreciation of its terse and clear statement of valuable facts and experience. Though I have endeavored to show that some of these, on closer scrutiny, demonstrate the weaknesses of the rigid gear construction, that does not detract from the fact of its being a worthy contribution to the subject of which it treats.

The facts stated in "Engineering" of May 7, 1920, page 599, of difficulties in Britain with second reduction pinions have deeply interested me. That difficulties with the second-reduction pinions of floating-frame gears have very seldom occurred—nearly all tooth breakages, as I am assured by the Westinghouse engineers, being confined to the first-reduction pinions—seems to add a material fact which justifies a rediscussion of the situation.

That many gears will not stand at sea nearly the load they would on land seems to be a common observation. According to Mr. W. R. L. Emmet (Vol. CIX, page 599) the safe load at sea in some of his gears was less than one-quarter of that on land. Again in "Shipping" (New York) for December 31, 1919, page 37, Mr. Hadley F. Brown very pertinently remarks, "The high speed turbine itself gives very little trouble aboard ship. This, however, is not the case with the reduction gears, which are usually of the double reduction type with a ratio of approximately 40 to 1. It follows that they must be large and more or less complicated, that they will require perfect alignment at all times (which is difficult aboard ship owing to the change in the vessel's base line from light to loaded draft, also the strain to the vessel from rolling and pitching in heavy weather), otherwise the gearing teeth would quickly wear out. After the foregoing difficulties have apparently been overcome, it is often found that the gearing teeth commence to deteriorate in a very short time in the form of pitting, which continues until the teeth give way from this cause. * * *

"One owner reports that when the vessel was light or in a partly loaded condition, the gears apparently functioned perfectly with very little noise, but when fully loaded the noise increased, and the pinions wore out in less than one voyage.

"Some steamship companies that have equipped their vessels with this installation find that they have to renew the gears from every four to six months, and have decided to replace them with reciprocating engines, while in other instances vessels with practically the same installation have been in continuous service on short runs for over six years, and at the last examination the gears showed no appreciable wear."

Mr. Brown has here forcibly described as coming within his experience much that was clearly foreseen before the floating frame was devised to remove these very difficulties. We have seen that the adoption of the empirical "$\sqrt{D}$ rule" was probably forced by the abnormal rise of elasticity of the larger gear casings. But in a double reduction gear which has, as is usual, both gears in one casing, the fore and aft length is very considerably longer than for a casing which would hold the second reduction gear alone; for in the former the second reduction helices have to be parted sufficiently to accommodate the first reduction gears. It is also much broader; and, where there are two high-speed and two low-speed pinions, as is most common, it is very much broader. Hence, if I am correct as to the reason for the "$\sqrt{D}$ rule," such a double reduction gear should require a lower power constant than a single reduction gear with the same diameters and length of helices as in the second reduction.

I think it is evident that the strain to which such a casing offers the least resistance is racking in which two diagonally opposite corners are supported and the other two pulled down. If anyone will take a fairly stiff piece of cardboard or a flexible book and submit it to such a strain he will easily convince himself that no other strain will so readily produce misalignment of the second reduction gear and pinion. And, also, that the alignment of the first reduction gear and pinion will not be so much disturbed, partly due to the center distances of the first reduction being smaller than that of the second; partly because this reduction lies near the stiff longitudinal wall; and, thirdly, as the average moment racking this part of the casing is smaller than the average moment affecting the parts nearer the longitudinal center line. This last reason applies with especial force to those double reduction gears which have two high-speed and two low-speed pinions, referred to above. Hence the second reduction gears should be most liable to damage and, as the pinion teeth are most frequently engaged, they should suffer most.

On the other hand, if the gear can be made nearly independent of such slight racking of the casing the results should be reversed; for a flaw in the material large enough to produce fracture in the small teeth of the high-speed pinion would be, relatively to the coarser pitch of the low-speed pinion, so much less important that frequently it would cause no damage. Hence, if I am right in claiming that the floating frame gives such immunity, the high-speed pinions should have more cases of broken teeth, which, I am informed, is the case.

It should not be necessary to lower the power constant of the second pinions and Fig. 2 shows that in these much higher tooth pressures and power constants are used in floating-frame merchant gears than in the single-reduction gears of British warships. These power constants cover a range up to 3.45 (without overload). Few have had serious trouble and the large proportion had none whatever, although many of the ships have sailed between one and two hundred thousand miles. Practically all of them show some pitting on the tooth surfaces but this, apparently, has no effect on the operation of the unit. The tooth surfaces are in good condition and in the few cases where any wear has occurred it has been due to bad oil or a dirty oiling system. On removal of these conditions wear stopped and the teeth repolished. In contrast with this the wear in rigid gears seems to be serious and progressive (Vol. CIX, page 599).

Mr. Brown, in the foregoing quotation, writes of the difficulties of attaining perfect alignment being *apparently* overcome; but the double checking of alignment, in shop and ship, specified by the Admiralty should

make everyone doubt if, in many cases, this is not more apparent than real. The statement he put in parentheses could well have been capitalized. The checking of alignment, on account of the great rigidity of the teeth, by direct measurement, is so delicate as to be practically impossible. Then, comparing different ships, there are variations in the rigidity of the gear casing, in the security of the bolting to the keelson, in the rigidity of the keelsons and hull, in the weather conditions to which the ship is subjected, and in the intelligent care of the engineers. No wonder there are anomalous cases; so that, from no obvious difference, some gears last well while others have short lives.

The slight and repeated racking of the bedplate of rigid gears by causing intense pressure first at one part of the teeth and then another would fully account for the excessive wear (Vol. CIX, page 599) experienced, and against this the plastic flow of the metal (Vol. CIX, page 600), which probably occurs to a slight extent, is no protection. I agree with the opinion of the writer of the article of May 7 (Vol. CIX, page 599) that the policy of decreasing the tooth load is not well based. As this would make the casing still larger and more elastic, unless cast much thicker, the racking would increase and, partly at least, decrease the expected advantage.

I think it will be conceded, on reflection, that the explanation I have put forward is not only consistent in all respects, but that it fully accounts for all the outstanding facts.

Let us test the accuracy of what I have stated by applying it to the case of the De Laval gear (Vol. CIX, page 600) that shows a wide discrepancy from ordinary practice which the writer thought requires accounting for. I have previously treated practically this same case in my Glasgow paper (T.I.E. & S., Vol. LXI, page 325, footnote), the figures from which I will use:—

This De Laval gear has a long slender pinion between two gear wheels. In the case I treated the pinion is 2.542 inch pitch diameter, or 0.038 inch larger than cited (Vol. CIX, page 600), and each helix is 9.5 inches long. There is no center bearing, so that the bearings are about 20 inches apart, or nearly 8 diameters. It meshes with a gear wheel on each side of 29.084 inch diameter. Thus, instead of the usual redundancy of a rigid gear—the pinion meshing with one gear and also constrained by the casing—we have that redundancy practically doubled. We have a large ratio of reduction—11.677—the double gear making the casing very broad and the long pinion making it long; and, hence, relatively to the double reductions under consideration, we have a very elastic gear case. Again, the pinion is so long and slender that the torsional error will be important. Lastly, unless exactly equal power is transmitted through each gear wheel, which can by no means be assured, the pinion is subjected to cross-bending which it is in no way calculated to withstand. The power constant might be expected to be very high as both sides of the pinion are driving, but it is only 1.738 and the tooth pressure per inch is 37 pounds.*

This result cannot be ascribed (as in Vol. CIX, page 600), to variations of torque and high angular momentum of the turbine wheel in the large classes of cases where the gears drive duplicate generators, centrifugal pumps, and centrifugal fans. I think, instead of being a puzzle, the very low tooth pressure used here was to be expected and fully sustains my position.

* I think the writer in "Engineering" has omitted to take account of both sides of the pinion driving and consequently has stated the tooth pressure at twice its actual value. If so, the discrepancy is more striking.

The proposals made in the May 7 article to meet the difficulties experienced in the pinions of double reduction gears, by fitting a flywheel aft of the second reduction gear and reducing the moment of inertia of the turbine rotor, are suggested by the existence of "overrunning" and hammering of the teeth (Vol. CIX, pages 599 and 600). But the evidence which one would expect if "overrunning," and, consequently, hammering were present is nowhere given. They would be accompanied by great noise and peening of the teeth, but neither is mentioned. They both occurred on a small gear constructed on a wrong principle which I saw tried in which a powerful short period vibration was sure to be set up. The teeth showed severe battering and the noise was so intolerable that only a short run was made. We would also expect breakage of the teeth to result from hammering, but it is stated (Vol. CIX, page 599), that "breakages have been astonishingly few." The damage complained of is, (*a*) excessive wear (Vol. CIX, page 599); which is much more likely to result from misalignment producing excessive pressure, and (*b*) pitting (Vol. CIX, page 599), which can hardly be ascribed to hammering as a principal cause, since the pitting usually stops while the hammering would occur at intervals during the life of the gear.

Further, the conditions which would produce serious hammering will rarely be present. Even where there is synchronous torsional vibration actual separation of the teeth cannot occur unless the vibration is intense, as there is the driving torque of the turbine which will always produce an enormous acceleration when all load is removed and will keep the contacts closed. I could not imagine an engineer continuing to run at a speed which would give such intense vibration, as he would naturally fear the ruin of his installation, and as a slight increase or decrease of speed would avoid synchronism and quiet the hammering. Also, if the vibration is powerful enough this exact synchronous speed will be unstable as it would lead, through the increased churning of the water by the propeller, to a decrease of efficiency and would require a greater torque than would correspond to this speed were no vibration present. Hence the power would have to be abnormally increased to attain the synchronous speed and, should this speed be passed in the least the improving propeller efficiency would cause the speed to rise toward its normal value for the torque being applied.*

But synchronous torsional vibration in smaller amount than would separate the teeth and cause hammering could still seriously raise the maximum tooth pressure. This would have little effect with the low designed pressures used in the rigid gears under discussion if there were not mis-

* This occurred on United States torpedo-boat destroyer *Hopkins*, the trials of which I conducted. The engines were reciprocating and had been designed so that there was a large second period variation of the torque; that is, the torque passed through two very pronounced maxima and minima each revolution. There was great vibration of the hull which I did not at first recognize as induced by torsional vibration of the after engine shafting. The forward engine had worked roughly from about 250 to 270 r.p.m., but the after engine, with full boiler pressure of 270 pounds per square inch and throttle wide open could not be forced above about 300 r.p.m. I found, on calculation, that the natural speed of torsional vibration for the forward engine shafting was 540 per minute and that for the after engine 618, giving critical r.p.m. of the engines as 270 and 309, respectively. On making changes to smooth the torque curve as much as practicable the engines ran readily through the critical speeds with little vibration. So great was the change that the after engine of the sister ship *Hull* ran 318 r.p.m. with an initial pressure of only 180 pounds per square inch in its high pressure card. I found an almost parallel case in United States Torpedo-boat destroyers *Lawrence* and *Macdonough*, regarding which I was consulted, and successfully applied the same remedy. For a much fuller account of the foregoing and the remarkable fall of propeller efficiency which I found, see "Engineering" (Vol. LXXV, page 302 *et seq.*, or J.A.S.N.E., Vol. XV, page 747 *et seq.*).

alignment causing a bad distribution of tooth pressure such as is shown in Fig. 1. I have been informed that the effect of such vibration has been observed in the markings on the teeth of the low speed gear, these appearing as zones of wear distributed round the circumference. I would expect, though I do not think I was so informed, that the number of these zones would be equal to the number of propeller blades.† So far as I know no one has observed such markings on a floating-frame gear although the designed tooth pressures are usually much higher.

If there is no close approach to synchronous vibration, as there would rarely be if the machinery is near the middle of the ship, requiring long shafting, the variation of torque can arise only from the action of the waves varying the resistance to the propeller. This is obviously the case in Fig. 1 (page 599). The ship seems to have been in a confused sea, from the intermittence of the pitching; and the waves, having a period of from 7 to 8 seconds, were from 250 to 330 feet long. This is "a fairly rough sea" (Vol. CIX, page 599), as described, but not extremely so. These conditions would not give rise to hammering as the accelerations corresponding to these long periods, even though the amplitudes were considerable, would be small and the acceleration due to the unresisted turbine torque would keep the tooth contacts closed.

Again, the largest variations of propeller torque from pitching would occur only under two conditions: (1) When the sea was very rough and the propeller blades rising much above the surface. An intelligent engineer would then be running at much reduced power and average tooth pressures would be very low. Or (2) when the vessel is light and the sea moderately rough, so that the propeller is sometimes submerged and then lifted nearly clear of the water. In this light condition also not nearly full power would be used and tooth pressures would be in little danger of rising to dangerous values. This is probably the case in Fig. 1 (page 599) as the ship is stated to have been in ballast, in which case it would not be near full displacement. In both these cases the straining of the ship would be the serious danger, as it would keep the alignment of the rigid gear disturbed. And I am confident that if damage occurs under these circumstances it should be ascribed to this cause.

If my arguments are correct, the introduction of a flywheel just aft of the gear is not advantageous. It is certainly not advisable with a floating-frame gear, as the evils it is proposed to cure do not exist. But if a flywheel is fitted it will produce two effects which in some cases will be important and detrimental:—

(*a*) In almost all cases the effect will be to change the position of the nodal plane and the natural period of torsional vibration of the shafting—usually to lengthen that period. Hence, if applied blindly it is as likely to bring about a condition of synchronism as to avoid it.

(*b*) The inertia of this large mass just aft of the gear casing may readily increase the straining and consequent misalignment of the gear, especially in a rough sea.

Finally, decrease of moment of inertia of the turbine rotor would certainly decrease shock. But, as Mr. K. Baumann, of the Metropolitan-Vickers Electrical Co., remarked when we were discussing this article in "Engineering," the most effective way of doing this is to drive the pinion through an elastic shaft as is done in all floating-frame gears. The shock

† Since writing the foregoing, a British friend has informed me regarding a tanker with the machinery aft and a four-bladed propeller. Zones of wear appeared on the gear wheel, these being 90 degrees apart, thus confirming the expectation formed.

due to the inertia of the turbine rotor is thus annulled and we have, further, the very great advantage of almost entirely separating the alignment of the turbine from that of the gearing.—"Engineering," May 20, May 27, 1921.

DOUBLE REDUCTION GEARING.

One of the most important problems confronting the marine engineering world today is the reliability and longevity of double reduction gearing for steam turbines. The experience in the mercantile marine during the last two or three years has certainly disclosed the fact that weaknesses have developed in some directions, but it appears to be by no means beyond the wit of man completely to eliminate the defects which have been proved to exist. In the early days of the Diesel engine a somewhat analogous situation arose in that the rate of progress in the size of units was too rapid, the nature of the conditions to be met was not appreciated, and the ground already traversed had not been consolidated before new steps were taken. Had this not been so, the present-day position of the internal-combusion engine would probably be far in advance of what now obtains. This policy produced a retardation which it has taken much time to neutralize, and only in the last year or so has real progress been commenced. Similarly in the case of the double reduction gear, history is repeating itself. The great success of the single reduction, followed by a long period during which the sizes of individual units gradually increased, appeared to imbue designers and marine engineers with a confidence, since proved to be unfounded, that the step to large double reduction gears was warranted, and many installations were proceeded with forthwith, practically on trust, on the assumption that the conditions obtaining were of the same nature as in the single reduction gear. It was certainly not anticipated in the early days that the introduction of an additional pair of wheels to the train between the turbine and the propeller shaft would be the cause of the difficulties in operation, which have arisen. Undoubtedly many such can be traced to unsuitable material, faulty workmanship and lack of care in maintenance of lubrication and alignment. nevertheless the characteristics of hammering, accentuated by the insertion of the intermediate wheel and pinion, associated with high tooth loading, and accompanied by excessive wear, pitting and flaking—chiefly of the second reduction elements—have occurred in many cases where the abovementioned causes were undoubtedly absent. These have been so detrimental in their effects that a large number of high-powered vessels are being forced to run at fractional powers until time and experience show that gradual increments of load can be applied with safety, the present limits being indeterminate. This certainly does not make for the good of the engineering prestige of the country, and it is hoped the more conservative rating now in force will mitigate to some extent the harm already done. Had the *festina lente* policy been adopted in this case the record of gear failures, more or less of common knowledge, would have been very much curtailed. In the papers which have been read before various professional societies and in the discussions, a certain amount of information has been placed at the disposal of the world, but much more is needed. In some cases the trouble has been accentuated by torsional oscillations of the shaft, particularly where this has been of short length, two interesting cases being brought forward at this year's Institution of Naval Architects meetings, but this appears to be only a con-

tributory and not the sole reason for the abnormal defects which have arisen, and further investigation is urgently necessary to elucidate the matter.

Reference to patent records will show that many devices are being put forward for giving flexibility to the main second reduction wheels and isolating them from endlong shock transmitted through the propeller shaft. Amongst these may be mentioned the insertion of a flexible coupling abaft the wheel and forward of the thrust block, a yieldable rim to the main wheel, provision in the second reduction element with teeth of spur form such as Maag gear—instead of double helical (German practice has largely been to fit teeth of this type), and many other schemes of a similar nature. The so-called nodal drive, wherein an attempt is made to locate the nodal point by the torsional oscillation of the shaft at the center of the main gear wheel, such point being determined by calculation, is another of the schemes which has been propounded and tried in at least one vessel recently, but the period of operation is, so far, too short to determine whether this has proved to be effective. All this, with the accumulated knowledge available as to the performance of ships in service, tends to show that most of the troubles experienced have lain in the second reduction element and that it is upon this that efforts should be concentrated.

A certain diffidence, perhaps natural under the circumstances, has been shown regarding publication of negative results and failures. It was Faraday who so strongly insisted on the importance of recording both successful and unsuccessful experiments, and the need is as great now as in his day. Obviously, the only method of progress is, as in all other branches of knowledge, to base our rules, formulæ, &c., on scientific lines proved to be correct by actual experience, subject always to the provision that the data already acquired have been irrefutably substantiated. That such have been obtained in the single reduction gears may be accepted without question, and it remains to take the symptoms of the troubles exhibited in the double reduction and to eliminate them in the light of acquired knowledge. In order effectively to do this, it is essential that all the facts available be at the disposal of investigators; obviously no single superintending engineer or firm of builders can have more than a limited amount of knowledge of the behavior of ships other than those built or run under their supervision. In the aggregate, however, there must be available a large volume of data, and it is earnestly suggested that the various firms or builders and superintending engineers combine to place this information at the disposal of an investigating authority, preferably a small joint committee, in which the two British Classification Societies could perhaps take the initiative. Such authority could tabulate the known facts as to failures in the double reduction gearing and issue a summary showing what have been the principal sources of trouble, so that steps may be taken, and research initiated where desirable, to remedy the evils disclosed. An appeal, therefore, is here made to (*a*) the technical committee of Lloyd's Register to inaugurate such a committee and (*b*) to engine builders and superintending engineers to come forward with the utmost candor and lay before such committee, if appointed, the results of their experiences with double reduction gear for the benefit of the engineering world as a whole, and Great Britain in particular.—"Shipbuilding and Shipping Record," June 30, 1921.

TENDENCIES IN MARINE OIL ENGINE PRACTICE.

During the winter session now drawing to a close, there have been a number of notable technical papers read before the learned Societies dealing with all branches of engineering, and where marine engineering is concerned perhaps the two most important have been "The Present Position of the Marine Diesel Oil Engine," by Mr. James Richardson, B.Sc., read before the Institution of Engineers and Shipbuilders in Scotland; and that on "Mechanical Gears of Double Reduction for Merchant Ships," by Mr. R. J. Walker, C.B.E., and Mr. S. S. Cook, B.A., before the Institution of Naval Architects. Selection of these papers is made for the reasons, firstly, that they deal with the two most modern developments in marine propulsive machinery, and, secondly, because we desire to draw attention to the trend of the discussions that ensued in both cases.

First, to deal with the oil engine question, as was perhaps inevitable, considerable attention was focussed on the relative merits of engines working on the four-stroke and the two-stroke cycles. Very definite statements were made in the paper on this subject, to the effect that most of the published data referring to power output obtained with two-cycle engines were incorrect, and these engines were credited with a power capacity that could not be sustained continuously at sea. This view was supported by reference to the submarine engine practice adopted in several important navies. Conditions in such service make imperative the reduction to a minimum of the space and weight of the main machinery, and it was noted in the paper that the four-cycle engine held a predominant position for satisfying these conditions.

On the theoretical side the author maintained that the limiting factor in respect of the power obtainable from any given size of combustion cylinder is the quantity of heat that can be passed through unit thickness of cast iron per unit of time for a given maximum temperature at the inner surface of the metal. The limit on this basis is largely independent of the piston speed. For instance, with a high mean effective pressure a low speed of revolution may give a reasonable figure of heat transfer through the metal surrounding the combustion zone, and conversely, a low mean effective pressure will permit safely of a high speed of revolution. In support of this contention, it may be noted that two-cycle engines, which have a higher mean effective pressure than is general with four-cycle practice, are mostly designed to run at a lower speed of revolution. Naturally in making comparisons on a mean pressure basis the mean effective pressure is that for the whole cycle. In the case of the four-cycle engine the cycle extends over two revolutions or four strokes, whilst with the two-cycle engine there is an explosion every revolution, or every two strokes.

The limiting rate of heat transfer is, of course, dependent on the material in use. Certainly for convenience of machine work and for general reliability, it is reasonable to assume, for the present at any rate, that an ordinary grade of good hard grey cast iron will be adopted and the limiting temperature of the inner face of the casting must not be such as to cause serious disintegration of the metal through the graphite plates and consequent liability to cracks, &c. Practice, at any rate with large four-cycle engines, has now reached such a stage that standardization has almost set in, and practice at sea has served definitely to give a safe figure for this question of heat transfer. Assuming, that the proportion of the heat of the fuel that has to be abstracted from the burning gases is more or less constant, and that the stroke-bore ratio can be assumed as fixed, so that the area of the piston is practically an exact fraction of the total area of the

combustion chamber, then the limiting condition can be expressed as pounds of fuel per hour consumed per square inch of piston area.

Taking the total amount of fuel per hour consumed in any cylinder and dividing it by the piston area in square inches the quotient should not greatly exceed 0.2 pound per square inch per hour. This is certainly a conservative rating, referring primarily to large engines and it could no doubt be safely exceeded for small cylinders. Large marine four-cycle practice over a number of years of continuous operation at sea, however, amply confirms the desirability of being conservative in this respect, indeed it was noted in Mr. Richardson's paper that even with the progress in design made within the last few years there has been generally a measureable increase in the weight and the space occupied by the slow-speed marine Diesel engine per horsepower developed continuously. This is due largely to the reduction in the rate of heat transfer.

The mean effective pressure for two-cycle engines on a brake horsepower basis appears from the table of mercantile engines given by Mr. Richardson to average about 66 pounds per square inch. The highest figure quoted is 73.5 pounds and the lowest 55, but the author held that it was very doubtful if a mean pressure higher than 55 pounds per square inch on a brake horsepower basis could be continuously sustained at sea. Three examples of two-cycle marine engines cited gave mean effective pressures of 73, 66 and 73 pounds per square inch on a brake horsepower basis, and the rate of heat transfer was equivalent to a fuel consumption of 0.39, 0.315, 0.345 pound per hour per square inch of piston area.

Corresponding to these figures certain stresses are developed in the material. On certain assumptions, it was concluded that the stresses arising from unequal expansion may in the three cases quoted amount respectively to 24,000, 14,900, and 15,000 pounds per square inch, the highest stress occurring in the largest engine. It is quite obvious that fractures in cast iron cannot be a matter of surprise when such stresses are imposed. As already mentioned the safe rate of heat transfer corresponds to a fuel consumption of 0.2 pound per square inch of piston area per hour. Hence, if the two-cycle engines be reduced in power output to the same basis the mean effective pressure will fall to a very moderate one of less than 55 pounds, and there will be, Mr. Richardson maintains, little, if any, gain in space or reduction in weight, as compared with the four-cycle engine.

To examine a little further this all important question which is raised in this paper, and so fully pursued in the discussion, it cannot, owing to lack of published definite data, be said to be conclusively proved that the rate of heat transfer equivalent to the combustion of 0.2 pound per hour per square inch of piston area is altogether established as the limit apart from the question of the quality of the fuel and the maintenance of the exhaust valves, matters which are not exactly common to engines of both cycles.

With a low grade of fuel oil, exhaust valve maintenance may be so onerous as to demand a reduction in power output with the four-cycled engine, apart from the heat transfer question proper. On the other hand, two-cycle cylinders with exhaust ports on one side and scavenging air inlet ports opposite, where cool air enters to clear out the hot gases, are certainly highly stressed, during full power running at a high rating, in this particular part of the cylinder, as it must be borne in mind that the necessarily high velocity of the issuing exhaust gases involves a high rate of transfer of heat to the cooled exhaust bars, and adjacent parts.

No doubt the quality of the metal surrounding the hot gases will be gradually improved. Much research to this end is now in progress, and in due course the results so obtained will be translated into foundry practice. To such metallurgical improvements, engine design and performance

will quickly respond. The special point we wish to urge is the fact that no data giving definite information regarding the two-cycle engine were given in the paper or discussion although there was ample testimony to the satisfactory performance of four-cycle engines. If there are two-cycle ships operating at sea with good results and working at high mean effective pressures and heat transfer figures, it would be greatly to the benefit of progress in marine engineering that the facts should be widely known.

Coming to the second paper it is probable that no marine engineering paper of recent times can have been so eagerly looked forward to as that of Messrs. Walker and Cook on "Mechanical Gears of Double Reduction for Merchant Ships," as there have been so many rumors of failures of mechanical double reduction gearing. Little enlightenment on a number of factors, however, was given by this paper, other than a certain amount of very interesting information on the one subject of torsional shaft vibration. It is, however, cheering to have the statement given by Engineer-Admiral Sir George Goodwin that failure was much less frequent than it had been twelve months ago, but whether a lessening of the tooth pressure or the exercise of greater care in workmanship, or both are responsible was not elicited. In this paper the authors quoted that in Great Britain and other countries (excluding America) the number of ships with double reduction gears built and under construction is about 220 representing a total of 1,150,000 horsepower. As successful examples only three designs—five ships—are quoted having constants in the equation for pinions over 10 inches diameter, viz., constant $= \frac{p}{\sqrt{d}}$ varying from 195 to 238. The statement that a constant between 180 and 220 is good practice, is made, although the authors hold that there is nothing to show that considerably higher loads than represented by the constants, could not be adopted. It is a well-known fact that a number of ships with double reduction gear are operating at sea at a fraction of full power, and so with a very much smaller tooth pressure than that designed, as was well pointed out in the discussion by Captain Onyon, M.V.O., R.N. Are there any double reduction gears running at sea continuously with constants of 220 or higher? Again, the questions involved are of such importance as to demand a solution which can only be obtained by the recording and publishing of actual details of performance. If a high standard of workmanship, materials and lubricants are the critical factors, then it is necessary that standards of such accuracy should be formulated, and definite means for securing these be made general. We do not desire at present to deal in detail with this question. It is evident, however, from the two discourses which are the subject of this article that nothing but gain can accrue from a close co-operation between the engineer and the shipowner. What is desirable is a free expression of experience and a complete recording and publication of full facts of performance. Along this path, and only by such means can these absorbing and highly important questions be raised from the present level of uncertainty and doubt to the realm of established experience.—"Engineering," April 8, 1921.

DIESEL ENGINE OIL.

The fundamental difference between the external-combustion engine as exemplified by the steam turbine, including, of course, its steam generator, and the internal-combustion engine, as exemplified by the Diesel engine, lies in the fact that in the former the combustion of the fuel takes place

in a piece of apparatus entirely distinct from the engine proper, while in the latter the fuel is burned in the engine itself. When one considers the conditions which exist in the furnace of even the most perfect form of steam boiler when oil fuel is used, the very high temperatures met with, the smoke which may be produced, the deposits in the form of ash, &c., and when one considers, further, that in the Diesel engine these same conditions are reproduced to a more or less similar extent, it is not difficult to realize why there is a certain amount of difficulty in producing a thoroughly reliable form of internal-combustion engine. This point of view of the Diesel engine as an arrangement in which the furnace is directly incorporated in the engine itself, while only giving a somewhat crude idea of the fundamental nature of the principle of internal combustion, serves to draw attention to the two main directions in which improvements in Diesel engine practice are being pushed forward at the present time. On the one hand we have investigations being made into the most suitable forms of fuel oil for Diesel engines and on the other we have researches into methods whereby the conditions produced by the combustion of existing forms of fuel oil can be most suitably withstood.

The problem necessarily arises: in which of these two directions lies the most profitable path for future improvements? We are led to this question by the fact that a "British Research Association for Liquid Fuels for the Oil Engine Industry" has recently been approved by the Department of Scientific and Industrial Research. It is to be assumed that this research association will carry out investigations in the direction of finding out the most suitable forms of fuel oils for Diesel and semi-Diesel engines, and how such oils may most economically be produced. At the present time so-called Diesel oil represents a grade of oil produced from what we may term crude oil in the correct sense of the term (that is, mineral oil just as it is obtained from the ground) by distillation of the more volatile fractions. It is not so light or so pure as either petrol or paraffin—gasolene and kerosene, as they would be termed on the other side of the Atlantic—but at the same time it is not so heavy or so impure as the residual oil that is now being so successfully employed for steam raising on board ship. But because Diesel oil is obtained by distillation, albeit after the lighter fractions have first of all been removed, it follows that the cost of this oil is greater than that of residual oil, and, in addition, it is not always to be obtained at those oil fuel depots where the residual oil for steam raising is available. If we decide that the success of the Diesel engine lies in the direction of producing economically an oil which yields the most satisfactory results from the point of view of reliability of the engine, freedom from choking of the fuel valves, freedom from carbonization of the exhaust valves and other parts of the working space in the cylinder, then we are committed to the duplication of arrangements for transport and for storage.

The other alternative is to so improve the engine that it can run equally well on heavy residual oil, both from the point of view of economy and from that of reliability and freedom from the necessity of frequent cleaning. If this can be achieved we shall require only one system for transport and storage of heavy oil, the fuel oil used for steam raising being equally suitable for Diesel engine fuel. It will be recalled that Mr. Schwab, of the Bethlehem Shipbuilding Corporation, claimed that his firm had succeeded in producing a two-stroke engine which marked a great improvement on any existing types, the improvement resting upon the claim that the engine could run on ordinary residual oil, such as was used in the furnaces of steam boilers. Mr. Schwab was quick to point out the

advantages to shipowners of such an engine as compared with the ordinary type of Diesel engine. These consist chiefly of lower fuel costs, since the price of "fuel oil" in the open market is generally less than "Diesel oil," and the possibility of enabling the vessel to bunker at any port where fuel oil depots exist, these being far more numerous at the present time than those where Diesel engine oil can be obtained. We have not heard, however, whether the engine has actually achieved in actual service at sea all that its sponsors claimed for it, but in any case it does appear as though this is the more profitable direction in which to look for improvements in Diesel engine design. Cases are on record of engines of this type running on lubricating oil—or, to be exact, a mixture of Diesel oil and lubricating oil—while vegetable oils have also been successfully employed. The problem appears to be mainly one of perfect atomization of the fuel, followed by an intimate mixing of the minute particles of fuel with air. If this can be accomplished and complete combustion of the mixture follows, there is no reason why the engine should not run continuously for long periods without undue carbonization of the various parts. It is apparent that if an engine which could run on residual oil or, indeed, on any liquid hydrocarbon capable of being pumped from the tanks to the engine, would yield the same degree of economy and reliability as is now obtained with the more or less refined Diesel oil, the obstacles to the adoption of the internal-combustion engine on merchant ships of small and medium size would be largely overcome.—"Shipbuilding and Shipping Record," May 12, 1921.

FUEL OIL FOR DIESEL ENGINES.

It has hitherto been customary to use a grade of liquid fuel known as Diesel oil in the machinery of motor ships. This is cleaner, of better quality, and lower specific gravity, than the fuel oil commonly employed under boilers in oil-fired steamers, but its price is 30 per cent higher, and shipowners are now asking whether the cheaper fuel cannot be satisfactorily utilized in motor-ships. Manufacturers of certain types of Diesel engine are endeavoring to prove that there is no objection to its employment, but there is considerable doubt whether this would apply to four-cycle engines where the exhaust valves are liable to give trouble if poor grade fuel is used. In the case of two-cycle machinery, in which scavenging is effected by means of ports and no mechanically operated valves are needed except for the injection of fuel and the admission of starting air, this objection disappears, and builders of two-cycle motors claim that Californian and Mexican fuel oils with a high percentage of asphalt, give results as good as those achieved when a more refined oil is used.

These claims have not yet been confirmed at sea, but prolonged trials have been carried out both on Sulzer and on Doxford two-cycle Diesel engines on the test bed. With an engine of the former type of 1,250 brake horsepower, a fuel consumption of 0.447 pound per brake horsepower hour was attained, using Mexican fuel oil, against 0.418 pound with gas oil, while with a 3,000 horsepower Doxford opposed-piston engine the fuel consumption when running on Mexican fuel was 0.441 pound. In both cases it is stated that no difficulties were encountered, and that a clear exhaust was attained, but the fuel had to be heated before being admitted to the cylinders. The utilization of these poor-grade fuels is a point of greater importance than appears on the surface, and, should it be shown that two-cycle motors can operate on them satisfactorily while four-cycle engines must burn special Diesel fuel, the advantage of the lower fuel consumption of the latter type will lose its importance.—"The Technical Review," June 21, 1921.

SUPERHEATING ON BOARD SHIP.

There has recently been running in our correspondence columns a discussion on the relative merits of the two types of superheater which are in use on board ship, viz., the uptake type and the boiler tube type. As this correspondence has now closed it may be of advantage to review the position dispassionately in an endeavor to determine what are the advantages that may be justly claimed by the advocates of each of the rival types. In the first place it may be noted that the two types of superheater under discussion are really capable of being classified respectively as the low temperature superheater and the high temperature superheater, and hence the problem becomes the old and oft-discussed one of the relative merits of different degrees of superheat.

In considering the question of the use of superheated steam on board ship, one is apt to lose sight of the fact that it is not only the problem of fuel consumption that has to be faced. If such were the case there would be little difficulty in deciding whether to employ a high degree of superheat, say 200 degrees Fahr. above saturation temperature, or a considerably lower figure, say 60 degrees Fahr. It can readily be shown that the increase of economy which results from the use of superheated steam is approximately 1 per cent for every 10 degrees of superheat, and if we could be assured that by the installation of a superheater in the boiler we should be merely absorbing heat that would otherwise pass away to the uptake, then it would be obvious that the higher the temperature of the steam passing to the engine the more economical would the whole plant be. But it so happens that while the fitting of a superheater, of no matter what type, does to a certain extent result in the utilization of a certain amount of the heat which would be wasted in a non-superheating boiler, it does also lead to a certain increase in the fuel consumption per pound of water evaporated. This increase in fuel consumption is more than compensated for by the increase in the total heat contained in each pound of steam, and hence the boiler with a superheater has generally a higher efficiency than one which is not so fitted.

The question is not, however, one in which we must regard the efficiency of the boiler alone. We must obviously consider the consumption of the engine also, and in estimating the relative value of high or low superheat the efficiency of boiler and engine taken together must form the criterion upon which our judgment is based. With superheated steam the consumption of the engine for a given power will be less than if dry saturated steam is used, the reduction in consumption depending upon the extent to which the temperature of the steam is superheated above saturation temperature. With a high degree of superheat we have a considerable economy in the steam consumption of the engine, but at the boiler there is the increased fuel consumption to provide this highly superheated steam as compared with a boiler generating dry saturated steam. With a low degree of superheat the increase in the efficiency of the engine is, of course, not so marked, but the increase in the fuel consumption at the boiler is correspondingly less. It is here that the figures quoted in the correspondence referred to are capable of being considerably amplified, and it would be of considerable value if a series of trials could be undertaken in order to determine the combined efficiency of engine and boilers with the different types of superheater and with different degrees of superheat.

There is, however, another aspect of the question which demands attention, and that is the effect of superheated steam upon the cost of upkeep of the engines. When highly superheated steam is employed, the effect of

the higher temperature on the different working parts of the engine, particularly at the high pressure end, is to lead to certain mechanical troubles which can certainly be reduced but hardly eliminated even when the greatest care is paid to these problems during the design of the engine. In the reciprocating engine this is largely a question of lubrication of the piston and the provision of a suitable arrangement of piston rings, and of a stuffing box for the high pressure piston rod. The design of the cylinder itself does not present any insuperable difficulty as the effects of distortion can be readily met. The other items referred to present considerable difficulty, and it is on this account that we still find many superintendent engineers who are adverse to employing superheated steam with reciprocating engines. With turbine vessels the use of superheated steam is becoming more general. The employment of the impulse principle at the high pressure end of the turbine enables the extent of the turbine which comes into contact with the high temperature steam to be kept within very small limits, since after expansion through the first set of nozzles the temperature falls to a more manageable figure. The high pressure portion of the casing is made of steel and the nozzles are kept separate from the casing giving them freedom to expand, with the result that the clearances are only slightly but not seriously affected by any distortion that may occur. It would appear then as though, despite a considerable amount of prejudice against the use of superheated steam, we are gradually becoming to regard the use of more or less highly superheated steam as good practice on vessels that are propelled by steam turbines, although with reciprocating engines the ordinary non-superheated boiler still continues to meet with favor.—"Shipbuilding and Shipping Board," June 30, 1921.

CASTING BRONZE PROPELLERS.

An interesting occurrence is recorded in the recent issue of the Transactions of the Institute of Marine Engineers, which indicates the great necessity for careful and slow cooling of bronze propellers after they have been cast. An engineer-lieutenant in the Navy witnessed the cutting up of a bronze propeller which had been scrapped, and noticed that while the metal showed normal over the whole surface on first being cut, the portions which were cut off and laid aside exuded matter which became green and increased in thickness the longer it was exposed to the atmosphere. This was only seen in the center of the casting, the outer metal showing bright and good for about an inch deep from the surface all around the blade. The thickness of the blade where cut was about 5 inches and the width of blade about 3 feet. The green growth was in some places ¼ inch thick, and on parts which have been longest exposed to the atmosphere had the appearance of fungus. It is suggested that the effects noted were due to the fact that the outer surface of the casting cooled before the center, and in contracting exerted forces which tended to separate the molecules of the center of the blade. Such a condition as existed at the center cannot but result in a weakening of the blade, and although a test bar may have been cast with it which would have stood the tensile test, the blade itself is unsound at the center and not up to the required strength. It is apparent that only by careful cooling can the possibility of such a defect be obviated.—"Shipbuilding and Shipping Record," Nov. 4, 1920.

DETERMINATION OF THE DIRECTION OF ATMOSPHERIC DISTURBANCES OR STATIC IN RADIO TELEGRAPHY.

By L. W. Austin, Ph. D.,

Head, U. S. Naval Radio-Telegraphic Laboratory, Washington, D. C.

The accidental discovery that the atmospheric disturbances, or static, come from more or less definite directions* was made independently by a number of observers in this country during the summer of 1918 in connection with the work then being done at various places to insure more perfect reception of European signals. It was then noted that along the coast of New England and the Middle States, the static appeared to come in general from the southwest. Very few quantitative observations, however, were made, but a general impression prevailed that the source of disturbance very probably lay in the hot plains of the Southwestern United States or Mexico.

WINTER AND SPRING, 1920.

In order to study static during the months when it is too weak in Washington to be of value for investigation, the writer was sent to Porto Rico in February, 1920.

San Juan.—On February 26th the apparatus was set up on the Naval radio reservation in San Juan near the old fortress San Geronimo, the in-

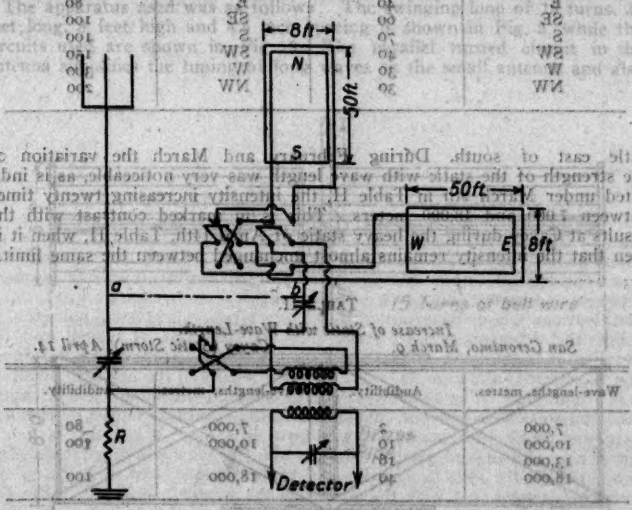


FIG. 1.

CIRCUIT FOR STUDY OF STATIC CHARACTERISTIC CURVE.

* Note: Suggestions that static might be directional had been made earlier by Marconi, Pickard and others. See G. W. Pickard, "Proc. I. R. E.," Vol. 8, page 358, 1920.

struments being sheltered in a tent. For the measurement of strength of signals and of the direction of the static it was not convenient to construct a swinging loop of sufficient size to permit satisfactory observations without amplification. Therefore, two standard 10 turn loops 50 feet long and 8 feet high with 6-inch spacing were placed at right angles to each other, with the apparatus so provided with switches that either one could be used alone or the two in parallel combination, either directly or in opposition.

The system was rendered unidirectional in the usual way by combining it with a small antenna. The circuits are shown in Fig. 1. This arrangement gave readings in eight directions, or every 45 degrees around the compass, and values could be interpolated so that the directions were known with a fair accuracy to within about 15 degrees.

A typical set of readings is given under the date of March 15th in Table 1. Here it is seen that the larger part of the static came from a point a

TABLE I.

Typical Observations on Southerly Static; San Geronimo, March 15.		*Observations During Static Storm: Static Mainly W by N but with much Local; Cayey, April 16.*	
Direction.	Audibility.	Direction.	Audibility.
N	6	N	200
NE	20	NE	100
E	40	E	80
SE	60	SE	100
S	70	S	100
SW	40	SW	150
W	30	W	300
NW	30	NW	200

little east of south. During February and March the variation of the strength of the static with wave length was very noticeable, as is indicated under March 9th in Table II, the intensity increasing twenty times between 7 000 and 18,000 meters. This is in marked contrast with the results at Cayey during the heavy static of April 14th, Table II, when it is seen that the intensity remains almost unchanged between the same limits.

TABLE II.

Increase of Static with Wave-Length. San Geronimo, March 9.		*Cayey (Static Storm), April 14.*	
Wave-lengths, metres.	Audibility.	Wave-lengths, metres.	Audibility.
7,000	2	7,000	80
10,000	10	10,000	100
13,000	16		
18,000	40	18,000	100

Loiza.—On March 19th the receiving apparatus was moved about twenty miles east of San Juan and about four miles from the ocean. The antenna loop system was identical with that at San Geronimo. The observations were continued here until March 31st, being taken in part by Gunner Taylor. The results here were similar in character to those at San Geronimo, though signals were somewhat weaker.

Cayey.—The observations at Cayey, altitude 1,300 feet, 30 miles from the north coast, extended from April 2nd to April 15th, the apparatus and arrangement of loops being the same as were used at the other stations. Observations showed that, taking into account the weakening of the signals with the advancing season, the reception at Cayey is decidedly superior to the stations along the north coast, while with the exception of the static storm, April 14th to 19th, the static conditions are more favorable. During this period the static, which had been mainly from the south in March, shifted so as to come principally from a little north of west (see Table I), and, since the periods of receiving difficulties seemed to be identical at Otter Cliffs and Cayey, it was concluded that the disturbances came from a common source. The afternoon static along the Atlantic Coast of the Northern United States had been found in general to come approximately from the southwest. The two lines of static direction from Otter Cliffs and Cayey would then cross each other in Mexico.

SUMMER OF 1920.

In the summer work of 1920 the attempt was made to extend our knowledge of the direction of static to cover the Pacific Coast region and to render our information regarding the conditions on the East Coast and in Porto Rico more definite.

The apparatus used was as follows: The swinging loop of 15 turns, 30 feet long, 8 feet high and 4.5 inch spacing is shown in Fig. 2, while the circuits used are shown in Fig. 3. The parallel turned circuit in the antenna simplifies the tuning of long waves on the small antenna and also

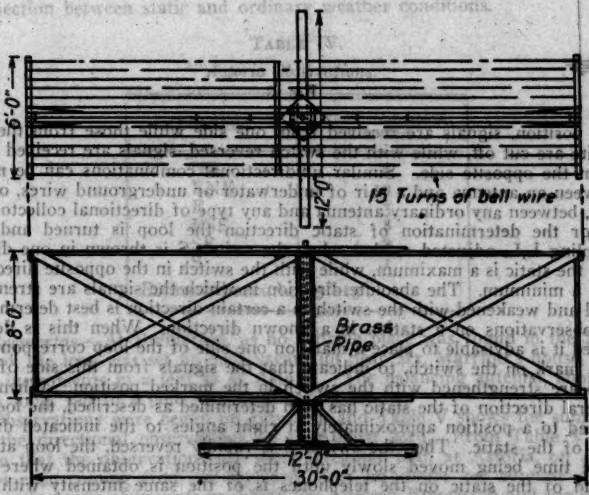


FIG. 2.

seems to give a better balance than is obtainable with series tuning. The resistance, R_1, 5,000 to 30,000 ohms, serves to reduce the signal strength on the antenna to approximately that of the loop, while R_2, 200 to 1,000 ohms, broadens the tune and enables the coupling to be changed without a too rapid shift of phase, thus rendering a complete balance easy. The balancing antenna used at different stations varied considerably in size. A single wire 100 feet long and 30 to 50 feet high was found to be satisfactory. The arrangement of coupling between the antenna and loop, as shown in Fig. 3, renders the loop unidirectional. With the switch S in

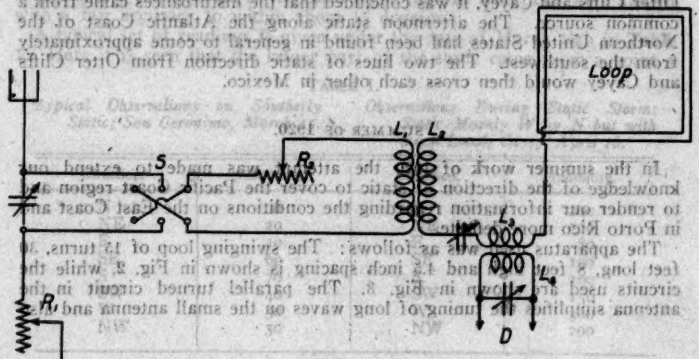


FIG. 3.

one position, signals are received from one side while those from the opposite are cut off, while with the switch reversed, signals are received only from the opposite side. Similar unidirectional combinations can be made between an antenna and a pair of underwater or underground wires, or, in fact, between any ordinary antenna and any type of directional collector.

For the determination of static direction the loop is turned and the coupling L_1L_2 adjusted so that when the switch S is thrown in one direction the static is a maximum, while with the switch in the opposite direction it is a minimum. The absolute direction in which the signals are strengthened and weakened with the switch in a certain direction is best determined by observations on a station in a known direction. When this is determined it is advisable to place a mark on one side of the loop corresponding to a mark on the switch, to indicate that the signals from this side of the loop are strengthened with the switch in the marked position. When the general direction of the static has been determined as described, the loop is turned to a position approximately at right angles to the indicated direction of the static. Then the switch S is rapidly reversed, the loop at the same time being moved slowly until the position is obtained where the sound of the static on the telephones is of the same intensity with the switch in its two positions. For exact readings the position of the loop expressed in degrees should be observed at which a difference in the intensity of the static is just detectable on each side of the zone of equality.

In the mean position between these two points, the loop is exactly at right angles to the static. This method of determining static direction is far more accurate than that of the simple unbalanced loop (radio compass). In fact, good readings can be obtained by the balanced method when no difference at all in intensity can be observed with the simple loop.

TABLE III.

Changes in Direction of Static with the Season.

San Geronimo, Mch. 1-18	*Loiza, March 19-31.*	*Cayey, April 14-25.*
80 per cent. South	50 per cent. South	30 per cent. South
20 per cent. W by N	50 per cent. W by N	70 per cent. W by N

During the past summer observations were taken daily at the Naval Radio Research Laboratory (Washington), and during certain periods at Astoria, Oregon; Bremerton, Wash.; San Francisco, Cal., and San Diego, Cal., with a few in Porto Rico and at other points.

Astoria.—The apparatus was set up on a dairy ranch about a mile from the radio station so as to avoid the influence of the station antenna and excessively strong interference. The loop was of the type already described and the antenna was a single wire running along the ridge pole of a barn 25 or 30 feet from the ground. The receiving instruments were covered by a tent and the work was carried on with the help of Radio Aid Marriott, of the Puget Sound Navy Yard, and his assistant. Observations were made between July 21st and July 31st, and the results of the measurement of static direction are given in Table IV. It was found in general that while the static was irregular in its direction, the individual observations fell into groups, the largest group indicating disturbances from a point about 20 degrees north of east. There seemed to be little connection between static and ordinary weather conditions.

TABLE IV.

Astoria Observations.

Direction.	Number of times observed.
NE	8
ENE	19
E	3
ESE	8
SE	8
S	1

Estimated accuracy 5°-15°.

Bremerton.—At Bremerton, as no suitable place was found in the Navy Yard, the loop was set up on a vacant lot near Mr. Marriott's house, with the instruments in a tent as at Astoria. The balancing antenna, about 90 feet long, ran to a pole in a neighboring lot.

Observations were begun on July 26th and Table V shows the summary of the directional observations up to August 23rd. From Table V it is seen that the observations are more irregular than at Astoria, on a few days even coming from the seaward side, no doubt on account of the Olympic range of mountains which lies between Bremerton and the ocean. In spite of the irregularity there seems to be a considerable concentration of static from the southeast.

TABLE V.

Bremerton Observations.

Direction.	Number of times observed.
WNW	1
NW	3
N	1
NE	4
ENE	5
E	13
ESE	13
SE	27
SSE	2

Estimated accuracy 5°–15°.

San Francisco.—The loop was here set up on the highest point of Goat Island, using as a balancing antenna a two-wire antenna about 50 feet high, originally intended for short wave spark work. Table VI shows the directional observations between August 11th and 31st. It is seen at once that the directivity of the static is entirely different from that observed at Astoria and Bremerton. Instead of being scattered over an arc of nearly 180 degrees, all the observations except one, which may have been influenced by some local conditions, fall within an arc of 10 degrees. This condition is remarkably favorable for a static barrage for reception from the west.

TABLE VI.

San Francisco Observations.

Wave-length . . . 8,000–12,000 metres.

Date and time.	Direction of static.
Aug. 11: 3 P.M.	E
12: 10 A.M.	E
13: 2 P.M.	4° S of E
14: 3 P.M.	E
16: 10 A.M.	E
16: 3:30 P.M.	4° S of E
17: 5:00 P.M.	5° S of E
18: 4 P.M.	9° S of E
19: 3 P.M.	9° S of E
20: 2 P.M.	10° S of E
21: 3 P.M.	8° S of E
23: 4 P.M.	2° S of E
24: 1 P.M.	4° S of E
25: 3 P.M.	8° S of E
29: 6:30 P.M.	8° S of E
30: 2 P.M.	8° S of E
31: 4 P.M.	3° S of E

Estimated accuracy 2°–4°.

San Diego.—In San Diego the loop was placed in front of the distant control receiving station on North Island, with the receiving set in one of the receiving booths of the station. The observations, extending from August 26th to September 10th, are shown in Table VII, the wave length

TABLE VII.

San Diego Observations.

Wave-length . . . . . 11,000–17,000 metres.

Date and time.	Direction of static.	Audibility.*
Aug. 26 : 3 P.M.	10° S of E	40
27 : 11 A.M.	E	40
27 : 3 P.M.	E	40
28 : 3 P.M.	5° N of E	10
30 : 3 P.M.	10° S of E	30
31 : 11 A.M.	10° S of E	30
Sept. 1 : 3 P.M.	10° S of E	15
2 : 3 : 30 P.M.	10° S of E	8
3 : 4 P.M.	10° S of E	8
5 : 3 P.M.	10° S of E	
8 : 11 A.M.	E	20
10 : 3 P.M.	E	40

Estimated accuracy 2°–5°, but absolute direction less accurately known than in San Francisco.

* Without amplification.

in most of the observations being about 11,000 meters. Here, as in San Francisco, the static was sharply directional from a point just south of east, none of the observations differing by more than a few degrees from this direction. The static intensity in general was not very different at the two places, with bad days perhaps a little more frequent at San Diego.

Washington.—During the summer, observations on the direction of static were made twice a day at the Naval Radio Research Laboratory. A summary of the afternoon results, July 1st to September 15th, is given in Table VIII. It was found that the direction of static is less sharply defined than at San Francisco and San Diego and that the reception bar-

TABLE VIII.

Washington Observations.

Direction.	Number of times observed.
W	1
W by S	5
WSW	25
SW by W	22
SW	11
SW by S	6
S	4

Estimated accuracy 3°–10°

rages are generally much less perfect. The prevailing direction appears to be about 30 degrees south of west, with a few observations scattered all the way between west and south.

Porto Rico.—Through some misunderstanding only a few observations on the direction of static have been forwarded from Porto Rico during the summer, but these indicate that the prevailing static has come from the south just as was observed last winter, instead of from a point slightly north of west, as found in the early spring experiments.

Our knowledge regarding the direction of static on the Gulf and Atlantic Coasts of our southern states is very meagre, but the little information available indicates that around New Orleans it comes mainly from a little west of south, while at Charleston it comes in part from the mountains a little north of west and in part from the southwest as at the more northern Atlantic Coast stations.

We may summarize our knowledge of directional static in the United States as follows:

1. The static on the Atlantic Coast of the United States comes in general from directions lying between south and west, largely from the direction of Mexico, but partly from the Allegheny Mountains.

2. The few observations on the Gulf Coast indicate a direction roughly southwest, *i.e.*, from Mexico.

3. On the Pacific Coast static is weaker than on the Atlantic and seems to come for the most part from nearby centers. In the north it is diffuse, but much of it seems to come from definite local centers among the mountains. Mr. Marriott has called attention to the fact that both at Bremerton and at Astoria a large part of the static comes from the direction of Mt. Ranier, an isolated peak and the highest in that part of the world. Further south, at San Francisco and San Diego, static is sharply directional and practically always comes from centers nearly east and probably among the nearby mountains.

4. In Porto Rico, according to our observations, static comes in general from one of two directions, either from a little east of south, probably from a center in South America, or from a center in the direction of southern Mexico a little north of west. This last center may also be the one which produces the southwest static in the eastern United States. In Porto Rico there is also during the warmer months considerable diffuse static of local origin.

5. In general we may conclude that static comes from the land rather than from the sea, and when it appears to come from the sea there is generally land in the given direction at no great distance.

6. It may be, judging from the analogy of signals, that static which increases with wave length in a marked degree as that at Washington and the southerly static in Porto Rico, comes from a great distance; while the static that varies little with wave length, as at San Francisco and San Diego, comes from centers not far away.

7. In Washington it is generally observed that the late afternoon static in summer is much more sharply directional than that of the forenoon, and that the directivity frequently becomes more pronounced as the static becomes more severe.

8. Two types of static in respect to tuning have been noted in our laboratory, one giving a pure shock effect is heard simultaneously over a wide range of wave lengths, and one in which the crashes are not heard simultaneously at different wave lengths. This last we have called the spectrum type, since it appears to consist of a large number of independent waves of different lengths forming a continuous static spectrum. There

is some reason to believe that the spectrum type forms a large part of the directive static.

9. At present it is impossible to formulate any completely satisfactory theory of the origin of static, but it appears probable that it originates in the upper atmosphere in powerful discharges between air bodies at different potentials,* though it is difficult to understand how such discharges which give rise to electrical waves more powerful than those from the largest radio station, can take place without luminous phenomena. If the disturbing waves are formed in this way in the upper atmosphere, the wave front undoubtedly spreads out until it reaches the earth, where it grounds itself exactly like the radio waves from an aeroplane and then moves off with a practically vertical wave front as if it had come from an antenna on the earth's surface.

The results of the observations thus far made, fragmentary as they are, indicate plainly the importance of taking static directional observations wherever radio stations are situated, and warrant plans for a general static survey which shall extend eventually to all parts of the world.—"Journal of the Franklin Institute," May, 1921.

H. M. AIRSHIP R 38.

At the Royal Airship Works, Cardington, near Bedford, the airship R 38, the latest and largest lighter-than-air craft produced in this country, is now all but complete and awaiting her trials. The Cardington Airship Works, it may be recalled, were constructed during the war for Messrs. Short Brothers, under a special arrangement with the Government. They cover a very large area and are completely equipped with all the various departments, the work of which goes to the making of an airship. Among other features, they include a very handsome range of offices, a shed capable of housing during construction two airships 700 feet in length, hydrogen plant on the Lane system, with a capacity for producing 100,000 cubic feet of purified gas per day, two gas holders with a capacity of half a million cubic feet each, a light alloy casting and rolling department, a meteorological and wireless station, metal and woodworking shops, engine test house, laboratory, canteens, a model village, and other adjuncts. We have no idea what the factory cost the nation, but that it represents an immense sum is obvious to all at first sight. Its contribution towards winning the war is represented by two airships which the Government is now anxious to give away, and one of which, we believe, succeeded in sinking a submarine, with a second doubtful. Since the end of hostilities the factory, taken over by the Air Ministry in April, 1920, has been engaged upon the construction of the airships R 37 and R 38. The R 37 is 80 or 90 per cent complete, but work upon her has been suspended. The R 38 is now virtually completed. When she leaves the works, building activity on the R 37 may be resumed, but otherwise the factory will probably be closed down, nor is it easy to conceive its re-opening for any purpose other than the building of airships.

The airship R 38 has already had a chequered history. She was designed in the spring of 1918 by the Admiralty airship staff, more or less as a reply to the large high-flying German craft of the "L 71" type. She was intended to be the first of four similar vessels, and was begun at Cardington by Messrs. Short in November, 1918. The Armistice led to the decision to cancel the construction of the four vessels, but the United

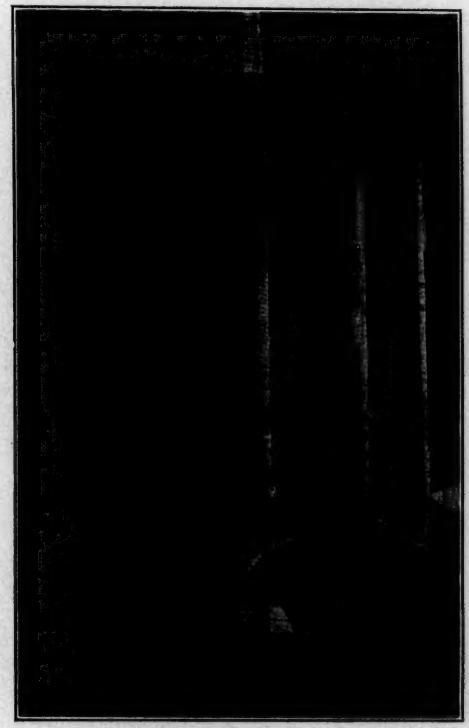
* See Pickard's article cited.

States Navy Department at the critical moment interposed with an offer to purchase the R 38 when completed. This offer was accepted by our Government, and an American crew is now in this country in training to fly the vessel across the Atlantic. The airship was thus designed by the Admiralty, begun by Short Brothers, and completed by the Air Ministry, and is to be sold to the United States Navy. For the greater part of the constructional work, the Air Ministry is responsible, the actual control of the building having been in the hands of Mr. C. I. R. Campbell, the superintendent of the factory.

In the accompanying illustrations we give some views of the vessel as we saw her in her shed on Friday of last week. Rigid airships in their general design are nowadays so largely based on the principles rendered familiar by Count Zeppelin's craft, of unfortunate memory and fate, that we need not stop to describe in detail the vessel as a whole, but will merely call attention to some of the features which may be held to distinguish the R 38 from her fellows.

The vessel is stated officially to be the largest rigid airship yet constructed in any country, its capacity being 300,000 cubic feet greater than that of the surrendered German airship L 71. Unlike other airships produced in this country—such, for example, as the R 33 and R 34, which were substantially copied from the design of the Zeppelin "L 30" class—the R 38 is an entirely British vessel in every respect. She was designed and has been completed for naval purposes, and has therefore been made as light as possible in order to enable her to ascend to a very great height. Germany's experience with airships during the war showed the paramount necessity of a high ceiling, and in the "L 71" class this desideratum culminated in the attainment of a maximum flying altitude of about 24,000 feet. In the R 38 the designed ceiling is about 25,000 feet. It should be explained, however, that this height may not now be attained, for the vessel has not been finished as originally planned. In the altered circumstances, advantage has been taken to introduce improvements and additions, such as bow mooring fitments, the added weights of which have somewhat reduced the vessel's designed performance.

With the exception of these later additions, everything possible has been done to reduce the weight and resistance of the parts of the vessel. A very noticeable item in this connection is the arrangement of the radiators in the engine cars. In the R 37 and earlier vessels the radiators are arranged to be raised and lowered vertically, so as to present a greater or less amount of their cooling surface outside the skin of the car. In the R 38 the radiators are permanently fixed inside the cars, the noses of which are provided with a rising and falling shutter or with louvres in order to regulate the cooling effect. The air after passing through the radiators is deflected to openings in the sides of the cars, so that the engine attendants do not suffer any inconvenience from it. From a door in the side of the car a step ladder slopes upward to a port hole in the hull of the vessel, whence internal steps lead down to the central walking way, which extends the whole length of the vessel. One side of the step ladder forms one of the struts to the car which it serves. In order to reduce wind resistance, the other side is arranged to be closed up against the first when the ladder is not in use, the rungs being hinged and the sides recessed to permit the folding action to be carried out. The closing of the ladder is made automatically to close the port-hole door in the main hull. It should be added that, unlike other designs, all the engine cars, of which there are six, are arranged as wing cars, the control cabin at the forward end alone being situated on the center line. We understand that the absence of center line engine cars was dictated by the impossibility of



THE CONTROL CAR.

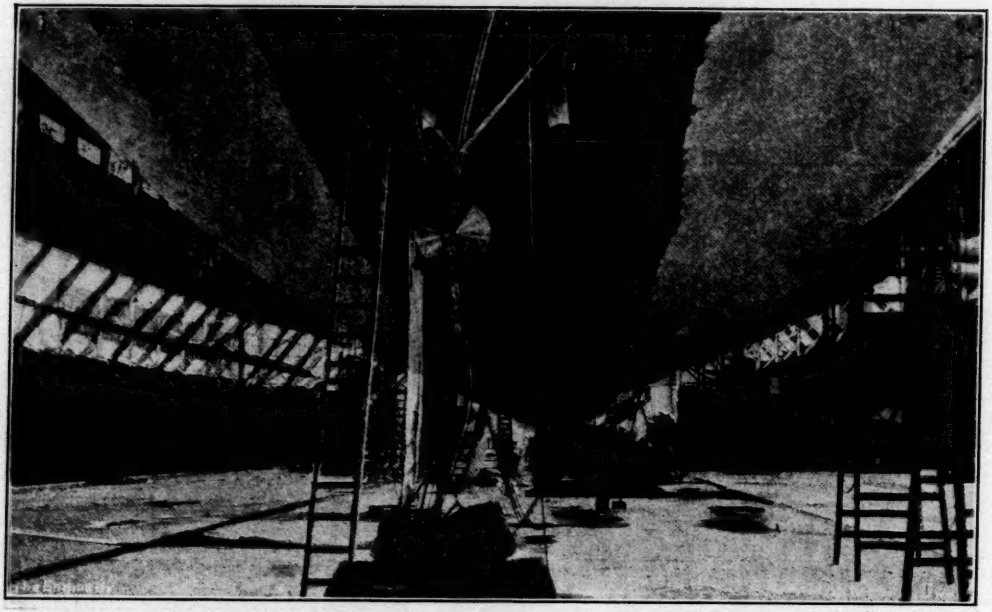
The Airship R 38.

BUILT AT THE ROYAL AIRSHIP WORKS, CARDINGTON, NEAR BEDFORD.

View From the Stern, Looking Forward.

Petrol Tanks and Central Gangway.

Internal Staircase In Nose.



WATER BALLAST DISCHARGE SHOOTS AND A TEMPORARY ANCHOR.

so placing them in a vessel, the hull of which was to be 85 feet, 4 inches in diameter, and which was to be built in a shed not more than 100 feet high. At the time of our visit and as represented in the accompanying engravings, the vessel was something more than half gassed, and was floating unsupported by cradles, but was anchored by weights and spring balances at eight points along her length.

Each engine car contains a 350 horsepower Sunbeam engine, so that the total power of the vessel is 2,100 horses. The attachment of the cars to the main framework is carried out by means of wooden struts and stay wires, and appeared to us to be distinctly on the side of flimsiness. A novelty, or so we understand, is to be found in the method of transmitting the propeller thrust to the hull framework. For this purpose, a steel cable is led backwards and slightly upwards from the center of the propeller boss to a point on one of the principal members of the framework of the hull. A wire similarly arranged stretches forward from the nose of the car to take the pull of the propeller when the engines are reversed. The weight of the car struck us as being insufficiently supported for inclined attitudes of the vessel's longitudinal center line. Four of the engines are fitted with exhaust cooking apparatus, to which the members of the crew bring their food by way of the folding step ladders to which we have already referred.

Running within the hull on its under side for nearly its whole length is a trapezium-sectioned passage, about 10 feet high and 10 feet wide on its lower and longer side. When the gas bags are fully inflated they form the roof, and the two sloping sides of this passage. The "floor," shown open in the engravings, is covered in by canvas. The actual walking way is a plank less than 1 foot wide, supported on the horizontal cross girders of the "floor." At one point this plank widens out into a ply-wood platform, to provide a mess room for the crew. Close at hand are the sleeping quarters, the bed frames being tubular members slung by wires from the roof of the passage. These frames are disposed on each side of the 1-foot gangway. One has, of course, to get used to sleeping on an airship with nothing but a layer of canvas between one and eternity. In places the 1-foot gangway is provided with a wire on each side at hand level for the support—more moral than material we should think—of those requiring it. Elsewhere a more solid form of support is obtained from the rows of petrol tanks, which at certain points are disposed on each side of the plank. These vessels each contain 190 gallons of petrol. There are fifty of them, so that when fully loaded the vessel can carry some 30 tons of fuel. Certain of the containers are arranged in slings in such a way that they can be instantly discharged bodily from the vessel to lighten her in case of emergency. Elsewhere the space on each side of the gangway is occupied by water ballast bags, emergency lubricating oil tanks and bomb racks. In the case of the water bags, each of which contains half a ton, the discharge of the ballast is controlled by the officer in charge who can eject at will a known quantity of water from any of the bags by pulling one of a series of levers in his cabin. For this purpose, the bags are calibrated, so that the quantity of water discharged from them when the valve is opened for a given number of seconds, from one upwards, can be tabulated for the officer's information. The discharge of the water ballast is chiefly resorted to for trimming the vessel when alighting, and is frequently a source of some unpleasantness to the landing party.

Towards the stern of the vessel the central gangway dips down by a series of steps into the interior of the lower vertical stabilizing fin, whence steps ascend again to a machine gun cockpit at the extreme tip of the tail. We are assured that this cockpit is the most comfortable position in the

vessel when in flight, as it is quite removed from the noise of the engines and from the draught. Going towards the bow, the gangway gives access to the control car, to which is attached a wireless room and the captain's cabin. Further on, the gangway leads to a flight of steps, which, ascending along the curved underside of the nose of the hull, ends at a door, through which the crew may enter or leave by way of a mooring mast. A "catwalk" runs along the whole length of the top side of the hull to permit the gas valves to be examined when the vessel is in flight. Access to this catwalk is gained by means of vertical rope ladders, passing upwards within tubular fabric casings between two of the forward and two of the after gas bags. As usual, automatic safety valves are provided on the gas bags at their lowest points. The gas discharged through them is led into a vertical trunk, and finds its way to an outlet on the upper surface at the maximum distance away from the engines.

The airship was designed to co-operate with the Grand Fleet in the North Sea, and has been completed purely as a naval vessel for its ultimate owners, by whom she will be given the distinguishing mark Z R 2. She is to be equipped with fourteen Lewis guns and one 1-pounder automatic gun, and will carry four 520-pound and eight 230-pound bombs. The bombs, it may be added, are carried and discharged vertically, with the nose end upwards, and not horizontally as is usual in bombing aeroplanes. They are thus called upon to execute a half somersault during the descent. The object of stowing them vertically nose upwards is to facilitate their being fused just before discharge.

The following is a tabular statement of some further data concerning the ship:—

Length	695 feet
Diameter	85 feet 4 inches
Capacity	2,700,000 cubic feet
Total normal lift	83 tons
Disposable lift	50 tons
Number of gas bags	14
Estimated full speed	69–70 m.p.h.
Cruising speed	60 m.p.h.
Endurance at full speed	5,000 miles
Endurance at cruising speed	6,500 miles
Normal crew	28–30
Estimated ceiling	25,000 feet

As for cost, no precise information is available regarding the money spent on the construction of this particular airship, but we understand that if another of her type were required it could be built for about one-quarter of a million pounds. It may be noted that a vessel of the R 38 design, adapted for commercial transport, could accommodate forty passengers and 2 tons of freight, and so loaded could perform a non-stop flight to Egypt in about forty-eight hours. As a result of the experience gained in the design and construction of the vessel, a new design has been produced for an improved type of airship with a gas capacity of about four million cubic feet. This vessel, it is stated, would be able to carry fifty passengers and 13½ tons of freight on a non-stop flight to Egypt in about forty hours.—"The Engineer," June 10, 1921.

THE STANDARDIZATION OF DATA FOR AIRSHIP CALCULATIONS.

By H. B. Wyn Evans, M.B.E., R.C.N.C.*

The different basic units employed, the alternative methods of calculation used, and the varying assumptions made in the design stages and later in the recording of performance data of "lighter-than-air" craft led the writer a year or two ago to broach a scheme embodying what is hoped will become a standard for such work among airship design staffs.

Since last May, and for some time previous to this, the Government Airship Design Section have based all their calculations for new design, recording of trial results and comparison with foreign ships on these standardized data.

LIFT OF HYDROGEN.

The "lift" of hydrogen is of course analogous to the buoyancy of water, and is the difference in weight between equal volumes of air and hydrogen under varying conditions of pressure and temperature. No reason was seen why the long standing figure of 68 pounds per 1,000 cubic feet of hydrogen should not be adhered to as a standard figure for the lift of hydrogen at sea-level. It represents a very good average condition of affairs in this country.

VOLUME OF GAS.

In actual practice the volume of a gasbag is determined by assuming it circular in section and of a radius equal to that of the circle circumscribing the outer points of the longitudinals, less an amount equal to the mean depth of the main and intermediate longitudinals, plus 3 per cent. The sum total of the capacities of the several gasbags calculated on these assumptions is taken as the gas volume of the ship.

In the case of a non-rigid ship the capacity is calculated by adding an allowance of 5 per cent to the volume of the envelope as designed, so accounting for stretch of the fabric due to inflation. For this calculation the ballonets are assumed empty.

GROSS LIFT.

By this is always understood the gross lift at sea-level under standard conditions, and is the product of the volume and the lift per unit volume.

STANDARD FLYING HEIGHT.

Owing to the considerable variation in the performance of internal-combustion engines with altitude due to the variation in atmospheric density, pressure and temperature, it became necessary to specify a height at which trials of ships should be run, and in specifying that height, to lay down standard conditions of the atmosphere normally found at that height. The height chosen for rigid airships was 2,000 feet above sea-level and for non-rigids 1,000 feet, and the values for the density, &c., of the air were taken in accordance with the Advisory Committee of Aeronautics' Reports and Memoranda No. 509.

* Précis of paper read at the Spring Meetings of the Sixty-second Session of the Institution of Naval Architects, March 17.

FIXED WEIGHTS.

We include in "Fixed Weights" all those weights which are constant and non-consumable, and which an airship would carry under all conditions of service. This list naturally contains the weight of structure, fabric, cars, machinery, &c. As regards machinery it has been decided to consider all the liquids in the fuel, lubricating, and cooling systems as integral parts of the engines and radiators. The fuel and oil in the service tanks are not included in fixed weights, but the containers (unless purposely made portable) are considered as fixed weights. Under "Fixed Weights" come the gun platforms and mountings, but not the guns or ammunition, which need not be carried under peace conditions, or, if carried, can be jettisoned in an emergency.

The wireless equipment and navigating instruments, handling and mooring ropes and appliances are now considered fixed weights, because without them the airship becomes unnavigable, and not in a condition to make a reasonable landing at a mast or otherwise.

DISPOSABLE WEIGHTS.

The crew, their food and fresh water are considered "disposable," because they can be disposed more or less at will to correct the trim of the ship in the air.

USEFUL LIFT.

The useful lift is obtained by deducting from the gross lift the following items:— (*a*) All fixed weights; (*b*) sufficient ballast for the ship to reach her standard flying height. This amounts to 3.2 per cent of the gross lift at 68 pounds per 1,000 cubic feet for non-rigids, 6.2 per cent of the gross lift at 68 pounds per 1,000 cubic feet for rigids; (*c*) emergency ballast, or "landing ballast"; (*d*) reserve fuel and lubricating oil for two hours' flight; (*e*) all tanks and containers regarded as slip or portable; (*f*) the approved reserve of water for the radiators and cooling system; (*g*) the crew, consisting of the complement as laid down, including their clothing and personal kit, and assumed to average 180 pounds *per capita*; (*h*) the approved spares and tools; (*k*) the approved equipment of the ship, including unfixed furniture and bedding, parachutes, life-saving appliances, oxygen apparatus, fire extinguishers, emergency rations (iron ration); (*l*) all other approved disposable equipment, as, for example, first-aid equipment.

The sum total of the weights of the items included under (*a*) to (*l*) above deducted from the gross lift give the amount termed "useful lift," which is available for the captain of the ship to divide in the most efficient manner between fuel and oil, passengers and freight, food and drinking water and armament and ammunition.

STATIC CEILING OR MAXIMUM STATIC HEIGHT.

It has been agreed to fix on that figure corresponding to the height attainable by the jettisoning of all "dischargeable weights."

SPEED.

It was decided to fix the speeds as those attained under the standard atmospheric conditions and to be calculated in knots. It was also agreed to record for all ships four distinct speeds, viz., maximum speed, normal full speed, cruising speed, and comparison speed: (*a*) *Maximum speed*,

to be that speed attainable under standard atmospheric conditions with engines developing their maximum power; (*b*) *normal full speed*, to be defined as 90 per cent full speed; (*c*) *cruising speed*, to be defined as 80 per cent maximum speed—this is equivalent to approximately half-power on the engines; (*d*) *comparison speed*, to be defined as 40 knots.

In the ascertaining of speed two methods are employed, one on a measured course of at least 10 miles in length, and chosen at the time of flight to be as nearly as possible in the direction of the prevailing wind, and the other on a triangular course nearly as possible equilateral with about 50-mile legs.

ENDURANCE.

To standardize the endurances for purposes of direct comparison between ships, it was necessary to standardize the "useful lift," and to attain this it was decided to consider the useful lift as made up entirely of fuel, lubricating oil, food, and drinking water for the crew, *i.e.*, assuming neither passengers are carried nor armament fitted. If A = total fuel and oil consumption in pounds per hour at a given speed, and B the consumption of food and water per hour for the crew, and the useful lift is U tons, then the endurance at the given speed is $\frac{U \times 2,240}{A + B}$ hours.

SOME USEFUL CONSIDERATIONS.

In all aircraft the relation useful load to weight empty or "dead load" can be considered the specific *useful carrying characteristic* of the craft.

Again, for an *economic commercial characteristic* we can relate the possible receipts to the working expenses.

To deal fully with these considerations would require a separate paper. It is merely referred to here to emphasize the necessity of standardizing data before making comparisons, which otherwise can so easily lead to wrong conclusions.—"Shipbuilding and Shipping Record," March 24, 1921.

SOME POSSIBLE LINES OF DEVELOPMENT IN AIRCRAFT ENGINES.*

By H. R. Ricardo.

In the following paper the writer's aim is to indicate certain possible lines of development and research which his own investigations and preliminary experiments have shown to be at least worthy of serious consideration. If we review the present state of the art we find the position to be substantially as follows: From a thermodynamic point of view the performance of the modern aero engine has approached so nearly to the ideal obtainable from the cycle on which it operates that there is little scope for improvement. Thermal efficiency or fuel consumption is now the all-important factor, but since the best modern aero engines are actually developing a thermal efficiency within 4 per cent or 5 per cent of the highest obtainable from the cycle on which they operate, it is evident that to gain any further improvement it will be necessary either to depart from, or at least to take considerable liberties with, the accepted cycle, or to modify the composition of the fuel, or both. The cycle on which all present-day aero engines operate is one in which an explosive mixture of

* Paper read before the Royal Aeronautical Society, December 16, 1920.

fuel and air is drawn into the cylinder compressed to the highest pressure permissible without detonation and ultimate pre-ignition, then ignited at constant volume and expanded until it occupies the same volume as before compression, after which it is released and the cycle is repeated. The theoretical efficiency of this cycle is given by the formula

$$E = 1 - \left(\frac{1}{r}\right)^{\gamma - 1}$$

This is known as the air standard efficiency; it assumes that the specific heat is constant at all temperatures, that there is no loss of heat and that there is no dissociation. According to this formula the efficiency is dependent upon r, the expansion ratio. In the ordinary cycle r is also the compression ratio, since compression and expansion happen to be equal, but it must be remembered that it is the expansion and not the compression ratio which governs the efficiency, and that the two need not necessarily be equal.

The most recent investigations on the properties of the working fluid carried out by Mr. Tizard and Mr. Pye and corroborated by the writer's experimental results, show that when due allowance has been made for the losses due to change of specific heat and to dissociation at the temperatures which actually obtain in the cylinder, the true limiting thermal efficiency becomes approximately $E = 1 - (1/r)^{0.35}$. This formula takes no account of the losses due to the direct passage of heat to the cylinder walls during combustion and expansion. It is clearly impossible to arrive at a really universal formula which will take this into account, since the proportion of heat lost must depend upon the form of the combustion chamber, the speed, and, in fact, on the individuality of each engine. In the most perfect case of an engine having a compact and symmetrical combustion chamber and running at a high speed, so that the direct heat loss during combustion and expansion is reduced to the absolute minimum, the highest attainable indicated thermal efficiency is given pretty accurately by the formula $E = 1 - (1/r)^{0.3}$. This allows for the minimum possible heat loss to the jacket walls and may be regarded as the absolute limiting thermal efficiency obtainable under the best possible conditions, assuming:—

(1) Perfect carburation and distribution.
(2) That the compression and expansion ratios are equal.
(3) That the mixture is homogeneous and of the most economical strength.

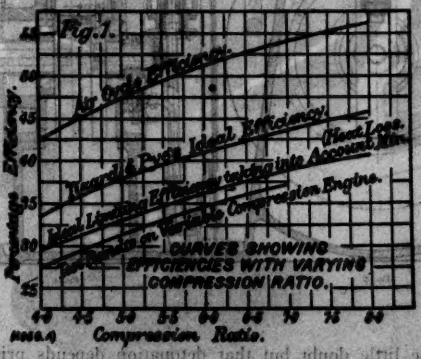
The following table (Table I) illustrated by the curves in Fig. 1 gives, in column (1) the air-cycle efficiency for a range of compression ratios from 4:1 to 8:1, column (2) Tizard and Pye's ideal efficiency, taking into account losses due to change in specific heat at high temperatures and to dissociation, column (3) the highest attainable indicated thermal efficiency assuming that the combustion chamber is designed to allow of the minimum possible heat loss, that the cylinder is of comparatively large capacity and that the revolutions are not less than 1,500 r.p.m. In column (4) are given the actual indicated thermal efficiencies as obtained in a special variable compression engine designed by the writer for research purposes, and in which every known artifice for obtaining the highest possible efficiency and power output has been employed. A photograph and sectional drawings of this engine are shown in Figs. 2, 3 and 4.

The difference between columns 3 and 4 indicates the scope left for improvement—it is very narrow. So long as the recognized cycle is adhered to, in its entirety, the importance of raising the compression and, therefore, the expansion is obvious. Now when working with all fuels belonging to the general group known as petrol the compression pressure which can be employed is limited by the tendency of the fuel to detonate and ultimately to pre-ignite. The explanation of the phenomena of de-

TABLE I.

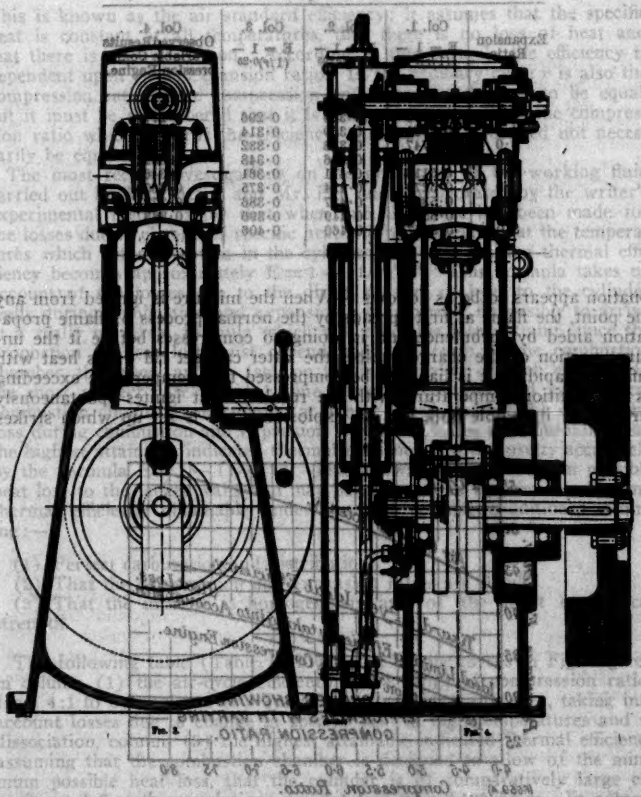
Expansion Ratio.	Col. 1. $E = 1 - \frac{1}{(1/r)^{\gamma-1}}$	Col. 2. $E = 1 - \frac{1}{(1/r)^{\gamma-\alpha}}$	Col. 3. $E = 1 - \frac{1}{(1/r)^{\gamma-\alpha}}$	Col. 4. Observed Results Variable Compression Engine.
4·0	0·4286	0·289	0·294	0·277
4·5	0·4581	0·310	0·314	0·297
5·0	0·4747	0·328	0·332	0·316
5·5	0·4944	0·336	0·348	0·332
6·0	0·5116	0·411	0·361	0·346
6·5	0·5270	0·424	0·375	0·360
7·0	0·5399	0·437	0·388	0·373
7·5	0·5394	0·449	0·396	0·383
8·0	0·5647	0·460	0·406	—

tonation appears to be as follows:—When the mixture is ignited from any one point, the flame at first spreads by the normal process of flame propagation aided by turbulence and in doing so compresses before it the unburnt portion of the charge; unless the latter can get rid of its heat with sufficient rapidity, it is liable to be compressed to a temperature exceeding its self-ignition temperature, with the result that it ignites spontaneously throughout its whole bulk and an explosion wave is set up which strikes



the walls of the cylinder with hammer-like blows, giving rise to the familiar noise known as "pinking." This explosion wave further compresses the portion of the charge first ignited, thus still further raising its temperature, and with it the temperature of the igniter points or any other partially insulated object in the neighborhood from which ignition first

started, to so high a temperature as ultimately to cause pre-ignition and loss of power. Pre-ignition, which is the ultimate limiting factor controlling the compression, never occurs under normal conditions with petrol, except as a result of persistent detonation. If detonation be prevented, a much higher compression can at once be used without any risk of pre-ignition, and a very decided gain both in power and efficiency obtained thereby.



There can be little doubt but that detonation depends primarily upon the normal rate of burning of the fuel, and this in turn depends upon the pressure, and, to a less extent, upon the temperature at the time of ignition. If means be adopted either for slowing down the normal rate of burning or raising the self-ignition temperature of the fuel, or both, detonation can be kept in control and a much higher compression ratio can

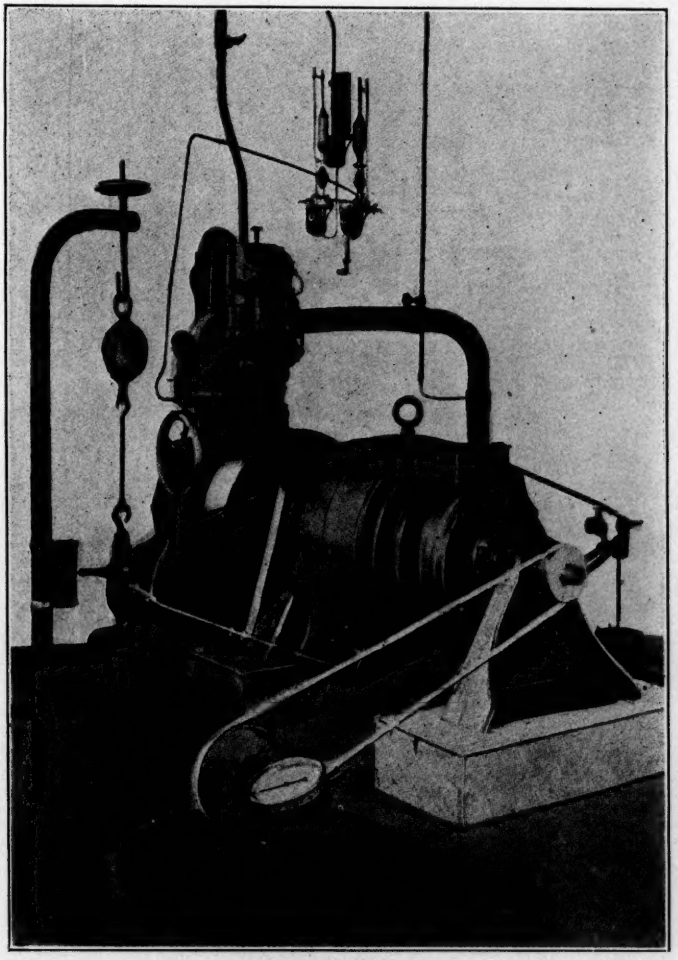


FIG. 2.

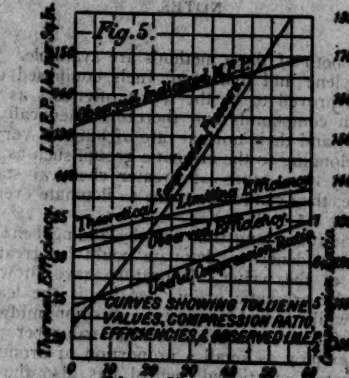


Fig. 5.
Thermal Efficiency
I.M.E.P. (lbs. per Sq. In.)
Compression Ratio
Compression Pressure, Lbs. per Sq. In.
Theoretical Indicated I.M.E.P.
Theoretical Efficiency
Observed Efficiency
Observed Compression Ratio
CURVES SHOWING TOLUENE VALUES, COMPRESSION RATIO, EFFICIENCIES & OBSERVED I.M.E.P.
Toluene Values.

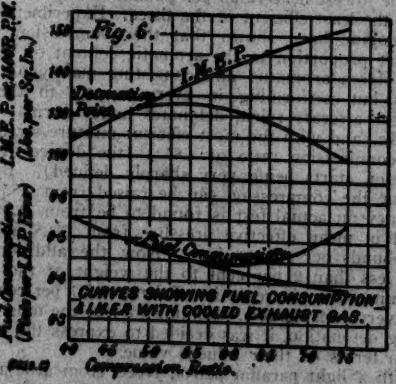


Fig. 6.
I.M.E.P. at 1500 R.P.M. (lbs. per Sq. In.)
Fuel Consumption (lbs. per I.H.P. Hour)
I.M.E.P.
Detonation Point
Fuel Consumption
CURVES SHOWING FUEL CONSUMPTION & I.M.E.P. WITH COOLED EXHAUST GAS.
Compression Ratio.

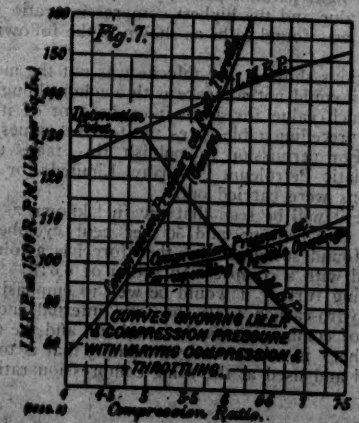


Fig. 7.
I.M.E.P. at 1500 R.P.M. (lbs. per Sq. In.)
I.M.E.P.
Detonation Points
CURVES SHOWING I.M.E.P. & COMPRESSION PRESSURE WITH VARYING COMPRESSION & THROTTLING.
Compression Ratio.

be used. Either or both of these methods are available. With the exception of ether, acetylene and hydrogen, fuels composed of light paraffin fractions have been proved to be the worst offenders as regards detonation—they are chain compounds and therefore chemically unstable, their ignition point is low, and their normal rate of burning very rapid. On the other hand, fuels belonging to the aromatic group, such as benzene, toluene and xylene are ring compounds of greater chemical stability and high ignition temperature, they cannot be made to detonate even with compression ratios as high as 7.5 :1.

It has been known for a long time that by adding benzol or benzene to paraffin petrols the tendency to detonate could be greatly reduced, but recent experiments at the writer's laboratory have shown that of these three members of the aromatic group, benzine is the least effective and toluene the most, while xylene occupies a position midway between the two. On account of their relatively low heat value per pound, it is naturally desirable to employ as small a proportion of aromatics as possible. Of the three aromatics mentioned, benzol has also the highest specific gravity and the lowest heat value per pound. It is, therefore, from every point of view the least efficient of the three. Experiments on the variable compression engine have shown that the compression pressure can be raised in direct proportion to the aromatic content of the fuel. A light paraffin freed from aromatics and consisting mainly of fractions of the paraffin series, but conforming in every respect to the Air Ministry's specification for aircraft spirit, detonates under normal conditions as to temperature, &c., and with the most efficient mixture strength and ignition timing, at a compression ratio of 4.85 :1 (the degree of compression at which detonation starts being very sharply defined). By adding 20 per cent of toluene the compression can be raised from 4.85 :1 to 5.57 :1, the gain in efficiency on actual test is found to be from 31.1 per cent to 33.5 per cent, and in mean effective pressure from 131.8 pounds per square inch to 140 pounds per square inch. Now the addition of 20 per cent toluene adds less than 2 per cent to the weight of the fuel per unit of heat and permits of an increase in efficiency of 7 per cent. The net gain is, therefore, very considerable. Finding toluene the most efficient medium for preventing detonation, it was decided to express the tendency of fuels to detonate in terms of their toluene value.

Starting with a light paraffin petrol, freed from aromatics, the relation between toluene value and the highest compression ratio which could usefully be employed was found to be as shown in the following table, and the curves in Fig. 5.

Later investigations showed that toluene was not the most efficient dope, and that, in fact, it could not compare with alcohol, though this fuel is not likely to be of much value for aircraft on account of its low heat value per pound. The preceding table gives the toluene values of a number of different fuels. For permission to publish this table the writer is indebted to the Asiatic Petroleum Company, Limited, for whom these and other investigations were carried out.

From this table it will be seen that the fuel known as hectar, and consisting of 50 per cent benzene and 50 per cent cyclohexane, which the Americans have found so successful, therefore has a toluene value of 48, and could be used with a compression ration of 6.6 :1.

Before proceeding further it would be well to emphasize that of all the known volatile hydro-carbon fuels the total internal energy (taking into account the heat of combustion on the one hand and the change in specific volume on the other) is substantially the same, that is to say, when completely evaporated and used at the same compression ratio, all fuels, irre-

Toluene Value.	Compression Ratio.	Ind. Mean Pressure as Found by Experiment.	Ind. Thermal Efficiency as Found by Experiment.	Limiting Ind. Efficiency.
0	4·85 : 1	133·5	0·311	0·327
10	5·20 : 1	135·4	0·323	0·338
20	5·57 : 1	139·7	0·335	0·350
30	5·94 : 1	143·0	0·347	0·361
40	6·32 : 1	144·9	0·355	0·371
50	6·67 : 1	147·5	0·363	0·380
60	7·05 : 1	150·0	0·373	0·388

Toluene Value.

Toluene	+	100
Benzene	+	66
Xylene	+	83
Ethyl-alcohol, 99 per cent.	+	166
Acetone	+	75
Cyclohexane	+	30
Carbon bisulphide	+	10
Methyl mercaptan	+	5 to 10
Ether	—	60

spective of their heating value, will give the same thermal efficiency and the same power to within about 2 per cent. The only exception is alcohol and the other members of its group; these, under normal conditions, give a slightly higher power because the increase of specific volume after combustion is very considerable, and also in practice owing to their higher latent heat they are seldom completely evaporated, with the result that a considerable amount of evaporation takes place in the cylinder during the suction stroke, thus both increasing the weight of charge and reducing the compression temperature. Popular theories that benzol or mixtures of benzol and petrol give higher power at the same compression than pure petrol, owe their origin to the fact that most engines have already too high a compression for efficient use with pure petrol, with the result that a late ignition setting and often an over-rich mixture also must be used. The addition of benzol in such a case permits of the use of full ignition advance and the most efficient mixture strength, and so gives rise to this very prevalent impression. Actually the total internal energy of, and therefore the power output available from, benzol, is very slightly less than petrol. Apart from varying the composition of the fuel, which is not always practicable, a somewhat similar increase in compression and therefore in efficiency can be obtained by the addition of inert gases which serve merely to delay the normal rate of burning. Experiments with pure aromatic-free petrol of toluene value 0 showed that the safe compression ratio could be raised from 4.85 to 1 up to 7.5 :1 by the addition of cooled exhaust gas. Fig. 6 shows the relation between mean pressure, thermal efficiency and compression ratio, when just sufficient exhaust gas was admitted in each case to check detonation. In dotted lines are shown, by way of comparison, the mean effective pressure and efficiency obtained with a fuel of high toluene value and of the same total internal energy. The divergence between the two mean pressure curves indicates approxi-

mately the proportion of inert gas added. It will be observed that the compression ratio can be raised at once from 4.85:1 to over 6:1 without any reduction in power whatever, and with a very substantial gain in efficiency; thus it is possible to improve the economy of an engine by as much as 6 per cent without affecting its horsepower one way or the other, by the mere addition of exhaust gas, costing nothing, and adding nothing to the weight of the engine.

To appreciate the possibilities of the use of exhaust gas in this manner, let us suppose that we have a fuel of toluene value 0. With such a fuel the highest compression ratio we can use if the engine is to be capable of running "full out" at ground level, and with an economical setting, is only 4.85:1, corresponding to a limiting thermal efficiency of 32.7 per cent. By the addition of cooled exhaust gas a compression ratio of say 7:1 giving a limiting thermal efficiency of 38.6 per cent could be used and still permit of the engine being run full out on the ground with perfect safety, and developing even at ground level very nearly the same power as the lower compression engine. As the machine ascended the quantity of exhaust gas would be reduced until at about 12,000 feet it could be cut off altogether. It will be seen that, in this manner, not only can a high compression engine be made to operate safely on the ground with any fuel, but that the control of exhaust gas can be made to afford a very efficient altitude compensator. By way of comparison, tests were run with varying compressions and with a fuel of toluene value 0 in order to ascertain the relation between mean pressure, compression pressure, and compression ratio when detonation is prevented by throttling. The results obtained are shown in Fig. 7, and require no particular explanation. It is interesting to note, however, that detonation became apparent at very nearly the same compression pressure in all cases. By way of comparison it will be noted that with this fuel the throttled engine with 7:1 compression ratio can develop only 57 per cent of its full power on the ground while the exhaust controlled engine can develop 84 per cent.

Safety Fuels.—A good deal of interest has been shown lately in the question of employing fuels of high flash-point to avoid fire risks. So far as the writer is aware, kerosene only has as yet been seriously considered. There are two possible methods of dealing with this fuel: (1) by vaporizing it and so using it in a normal type of engine; (2) by injecting it into the cylinder as a liquid, either during the suction stroke or at the end of compression. With regard to the first method, commercial kerosene consists almost entirely of heavy fractions of the paraffin series. These are all chain compounds, and their chemical stability decreases with increase in molecular weight. From the point of view of detonation, therefore, kerosene is one of the most troublesome fuels in existence. Further, in order to vaporize a reasonable proportion of it, it is necessary to raise its initial temperature to certainly not less than 60 degrees C. This means a reduction in the weight of charge of at least 20 per cent as compared with petrol, and a corresponding reduction in mean pressure. Further owing to its chemical instability on the one hand and the high compression temperature resulting from pre-heating, the limiting compression is reduced to about 4.2:1, corresponding to a limiting thermal efficiency of only 30.2 per cent and a limiting indicated mean pressure of only about 115 pounds per square inch, or, say, 100 pounds per square inch brake pressure. Again, no means have yet been discovered of preventing the heavier fractions condensing on the cylinder walls and passing down into the crank-case, where they soon prove destructive to the bearings, &c. So serious has this trouble proved in the case of stationary kerosene engines that so far the only kerosene engines of normal type which

have given consistently satisfactory results over long periods are those in which the working parts are open and each bearing is lubricated individually. Although detonation can be kept in check and a comparatively high compression ratio employed with the help of the addition of exhaust gas, yet the low-power output, the condensation trouble, and the low efficiency are such serious drawbacks as, in the writer's opinion, to put kerosene out of court as a fuel for existing types of aero engines. The alternative method of injecting the fuel is not much more hopeful so long as it is applied to the existing type of engine. If the fuel is injected on the suction stroke one avoids the loss due to pre-heating, and can, therefore, use a higher compression and obtain considerably higher power, but the condensation trouble becomes more serious than ever, while the problem of measuring and pumping small quantities of fuel and maintaining correct proportions between the fuel and air at all loads and speeds is no easy one.

Lastly, if the fuel be admitted at the end of compression and ignited on entry by means of a hot plate or other igniter, the very formidable difficulty of so pulverizing and distributing the fuel that each particle can find at once the necessary air for complete combustion has got to be tackled; it is one which is very familiar to the author from bitter experience with Diesel and semi-Diesel engines. There is, however, another way of dealing with the high flashpoint fuel problem which, in the writer's opnion, is the most hopeful at the moment. Many natural kerosenes contain a considerable proportion of heavy aromatic hydro-carbons having the same characteristics as regards flashpoint as the kerosene of which they form part. These aromatics burn with a smoky flame, and are therefore very objectionable when the fuel is used as an illuminant. Recently steps have been taken to isolate and remove these heavy aromatics, and at the present time they are being removed at the rate of several thousand tons per month. Their use as a safety fuel for aircraft engines is worthy of careful consideration. Owing to their almost complete immunity from detonation they can be used with a very high compression ratio, even after pre-heating in a vaporizer. Experiments made with these aromatic extracts show that with an inlet temperature of 60 degrees C. it is still possible to use a compression ratio as high as 6·1, even and 6·5·1, with the result that the efficiency is very high and the power output equal to or very nearly equal to that obtained with ordinary petrol of low toluene value. Direct comparative tests carried out with paraffin and samples of these aromatic extracts gave the following results:—Kerosene, sp. gr. 0.812; I.M.E.P., 111.0; fuel pt. per 1 horsepower hour, 0.595; aromatic extracts, sp. gr. 0.884; I.M.E.P., 125.5; fuel pt. per 1 horsepower hour, 0.42. In both cases exactly the same vaporizer temperature was used, the only difference being in the compression ratio employed. The results obtained are, in the writer's opinion, sufficiently encouraging to justify further investigation. The difficulty of condensation still remains, but this appears to be less serious than with kerosene, since the freedom from any tendency to detonate permits of more pre-heating, while it is open to question whether the heavy aromatic condensate is as destructive to lubrication as the paraffin.

Influence of Mixture Strength.—In the earlier part of this paper the writer has shown that because of the losses to dissociation, change of specific heat and direct heat losses, the limiting efficiency obtainable under the best conceivable conditions is only about 70 per cent of the air cycle. Now each of these sources of loss is a direct function of the maximum temperature, which in turn is dependent upon the mixture strength. When the mixture is so proportioned that the whole of the available oxygen is

just combined, the maximum temperature rises to approximately 2,500 degrees C., and the mixture strength is then approximately 47 foot pounds per cubic inch. As the mixture is weakened the maximum temperature is, of course, reduced, at first only very slightly, but so long as a homogeneous mixture is employed it is not possible to reduce the mixture to below about 40 foot pounds per cubic inch, without serious loss of efficiency due to incomplete combustion, owing to the limited range of burning of all volatile hydrocarbon fuels. The writer has carried out on behalf of the Asiatic Petroleum Company Limited, a very large number of tests on about 40 different fuels in order to ascertain the relation between mixture strength, power and economy. Except for insignificant variations, the characteristic efficiency and power obtained by gradually weakening the mixture is the same for all fuels and at all compressions, excepting alcohol, which on account of its greater latent heat and its large increase in specific volume gives increasing power as the mixture is enriched for a long period after the point of complete combustion has been passed.

The curve (Fig. 8) shows the relation between thermal efficiency and mixture strength expressed in terms of mean pressure. The example shown is taken with benzol at a compression ratio of 6:1 and, with but infinitesimal variations, it may be taken as applying to any fuel except alcohol. It will be observed that maximum efficiency is obtained when the mixture strength is such that the mean effective pressure is about 3 per cent below the maximum. Any further weakening of the mixture results merely in loss of efficiency due to incomplete combustion. Now were it possible to control the power output by mixture strength alone, and still obtain complete combustion, it is clear that the maximum temperature would then be proportional to the load and would diminish as the load is reduced. As the temperature diminished so also would the losses due to dissociation, change of specific heat, and direct heat loss diminish until at the point of no load and, therefore, of no heat supply, they would disappear entirely and the limiting efficiency would be virtually coincident with the air cycle. The accompanying curve (Fig. 9) shows how, under these conditions, the limiting thermal efficiency would vary with the load. In this diagram the horizontal line denotes the air-cycle efficiency, which, since it takes no account of heat losses, &c., is constant for all loads, the sloping line denotes the theoretical limiting efficiency over the range from no load to full load, the third line represents the limiting efficiency with minimum heat losses, and the fourth the actual test results obtained over the range of mixture strength available with a homogeneous charge. While it is not possible to weaken the mixture strength so long as the charge is homogeneous, it is possible to do so by means of stratification, that is to say, by supplying the cylinder with a relatively small charge of combustible mixture and admitting separately a large charge of air, keeping the two separate until after ignition. To do this it is necessary to reconcile two conflicting conditions—the two portions of the charge must be prevented from mixing till after ignition, and at the same time there must be sufficient turbulence in the combustible charge to ensure rapid combustion. These two conditions are not irreconcilable, and the writer has succeeded experimentally on two engines in obtaining the whole range from dead light to full load by controlling the fuel alone. Under these circumstances not only is the efficiency on reduced loads far higher than could be obtained by any other means, but the heat loss is so low that a water-cooled engine can be run at reduced loads for any length of time without cooling water.

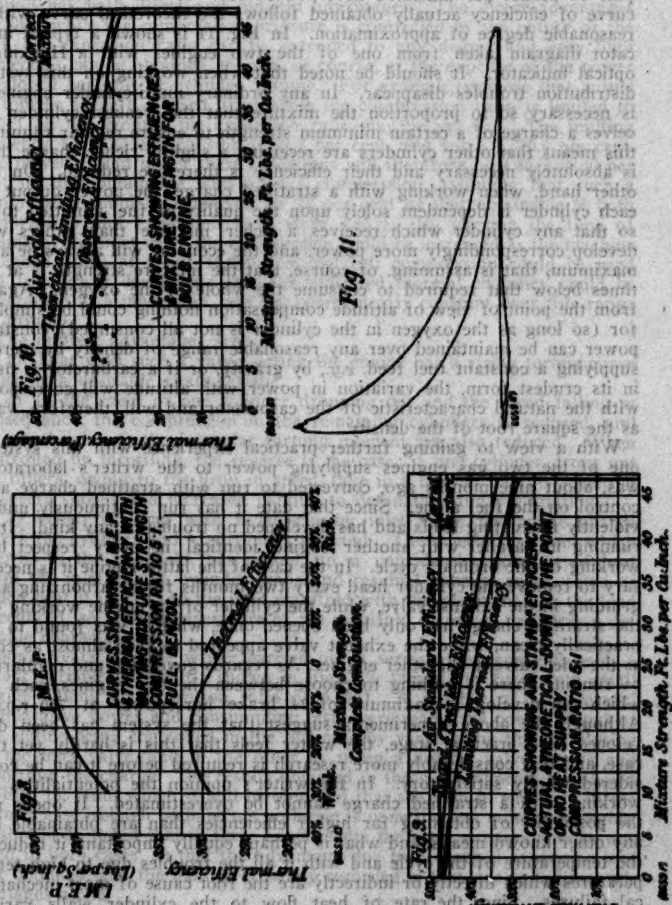


Fig 10.
Air Cycle Efficiency
Theoretical Working Efficiency
Observed Efficiency
CURVES SHOWING EFFICIENCIES & MIXTURE STRENGTHS FOR DIESEL ENGINE.
Thermal Efficiency (Percentage)
Mixture Strength. Ft. Lbs. per Cu.Inch.
Fig 11.
Fig 8
I.M.E.P
CURVES SHOWING I.M.E.P. & THERMAL EFFICIENCY WITH VARYING MIXTURE STRENGTH COMPRESSION RATIO 5·1. FUEL BENZOL
Thermal Efficiency
Mixture Strength. Complete Combustion.
I.M.E.P (Lbs. per Sq. Inch.)
Thermal Efficiency
Fig 3
Air Standard Efficiency
Actual Cycle Efficiency
Working Thermal Efficiency
CURVES SHOWING AIR STANDARD EFFICIENCY, ACTUAL & THEORETICAL—DOWN TO THE POINT OF NO HEAT SUPPLY. COMPRESSION RATIO 6·1
Thermal Efficiency
Mixture Strength. Ft. Lbs. per Cu.Inch.

The accompanying curve (Fig. 10) shows the efficiency actually obtained in one experimental engine with a compression ratio of only 5:1. It will be observed that it rises to no less than 37 per cent at about one-third full load corresponding to a fuel consumption of just under 0.36 pint of benzol per indicated horsepower-hour. It will be seen that the curve of efficiency actually obtained follows the theoretical curve with a reasonable degree of approximation. In Fig. 11 is shown a typical indicator diagram taken from one of the two engines with a Hopkinson optical indicator. It should be noted that when working on this system distribution troubles disappear. In any ordinary multi-cylinder engine it is necessary so to proportion the mixture that the weakest cylinder receives a charge of a certain minimum strength to ensure regular running; this means that other cylinders are receiving a slightly richer charge than is absolutely necessary and their efficiency is therefore reduced. On the other hand, when working with a stratified charge, the power output of each cylinder is dependent solely upon the quality of fuel admitted to it, so that any cylinder which receives a richer mixture than others will develop correspondingly more power, and the economy will always be at a maximum, that is assuming, of course, that the mixture strength is at all times below that required to consume the whole of the oxygen. Again, from the point of view of altitude compensation nothing could be simpler, for (so long as the oxygen in the cylinder is not all consumed) constant power can be maintained over any reasonable range of density by merely supplying a constant fuel feed, *e.g.*, by gravity, or if a carburetor is used in its crudest form, the variation in power with altitude will correspond with the natural characteristic of the carburetor and will, therefore, vary as the square root of the density.

With a view to gaining further practical experience with this system, one of the two gas engines supplying power to the writer's laboratory was, about nine months ago, converted to run with stratified charge and control on the fuel alone. Since that date it has run continuously under violently fluctuating loads and has developed no trouble of any kind. It is running in parallel with another engine identical in every respect but working on the ordinary cycle. In the case of the latter engine it is necessary to remove the cylinder head every two months for decarbonizing and grinding in the exhaust valve, while the cylinder of the engine working on the stratified charge has only been opened once, when it was found to be practically clean, while the exhaust valve appeared to keep almost as cool as the inlet valve in the other engine. As regards governing and regularity of running there is nothing to choose between the two engines, each of which can develop a maximum of 24 brake horsepower at 750 r.p.m. Although the above experiments suggest that the system has been developed to a practical stage, the writer feels that this is hardly yet the case, and that considerably more research is required before it can be considered wholly satisfactory. In the writer's opinion the potentialities of working with a stratified charge cannot be overestimated. It opens up the possibility of obtaining far higher efficiencies than are obtainable by any other known means, and what is perhaps equally important, it reduces the temperature of the cycle and with it all the troubles due to high temperatures which directly or indirectly are the root cause of most mechanical failures. Since the rate of heat flow to the cylinder walls varies roughly as the cube of temperature, and the power output practically directly as the temperature, it follows that quite a small reduction in power will reduce the heat losses to an extent that must render air-cooling quite a simple problem.

The possibilities of working with a short compression and long expansion stroke deserve careful consideration. In effect this can be accomplished by the simple expedient of closing the inlet valve late, so that compression does not start until well up the compression stroke; this method has both direct and indirect advantages. The direct advantages are that while the compression pressure is controlled by the nature of the fuel, the expansion ratio can be extended to any degree and very high efficiencies can be obtained, though, of course, at the expense of the power developed per unit of cylinder volume. For example, suppose that a fuel of toluene value 0 is used, then while the compression ratio is limited to 4.85:1 on the ground, the expansion ratio may be say 8:1. The limiting efficiency for 4.85:1 expansion is 32.7 per cent, and for 8:1, 40.6 per cent. The power output under these conditions will therefore be $4.85/8 = 60$ per cent of that obtainable with an 8:1 compression, assuming that such a compression could be employed, or 73 per cent of that obtainable if both compression and expansion ratio were 4.85:1. By varying the time of closing of the inlet valve the compression could be increased as the machine ascended, until at about 15,000 feet the full compression could be used and full power developed; thus the indicated thermal efficiency could be maintained at a maximum, and the power nearly constant over this range of altitude.

The indirect advantages are:—

(1) That with such a valve setting the engine has a rising torque curve which is a desirable characteristic.

(2) In the event of one cylinder dropping out and the speed falling in consequence, the compression in the remaining cylinders is reduced, and the shocks due to the irregular turning moment are also reduced. When controlled by throttling, the reverse is the case; if one cylinder drops out the others, owing to the drop in speed, take in a heavier charge, resulting in severe shocks and increased liability to detonation and pre-ignition.

(3) When working with a late-closing inlet valve the whole charge enters the cylinder and a portion is rejected. The rejected portion, which returns to the manifold, has picked up a considerable amount of heat from the inlet valves, cylinder walls and residual exhaust gases, some of which heat it imparts to the inlet manifold with the result that, as the load is reduced, so is the temperature of the manifold increased, which is a desirable characteristic.

Some years ago the writer carried out a series of experiments with a patent variable inlet cam (shown in Figs. 12, 13 and 14) fitted to a small engine having an expansion ratio of 5.95:1. A number of very careful comparative power and consumption tests were made, the power output of the engine being controlled in the one case by varying the time of closing of the inlet valve, and in the other by using a normal valve setting and throttling the charge. The results obtained in these experiments are shown in Fig. 15, from which it will be observed that the gain in efficiency in the former case, though perhaps not so large, is none the less quite appreciable. It should be noted that in these experiments the same expansion ratio was used in both cases, so that the advantage due to prolonged expansion was not obtained, and the gain in economy recorded is that due to indirect advantages alone.

In aircraft engines when one is working over a large range of atmospheric density the question always arises—at what density the engine shall be designed to give its best performance or at least to develop its full power. Until comparatively recently all engines were so designed that they could develop their full power at ground level, without pre-ignition, without overheating, and without overstressing the parts. During the war,

Fig. 12.

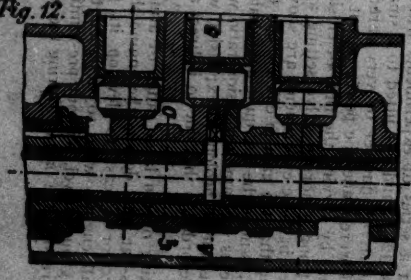


Fig. 13.

SECTION A. B.

Fig. 14.

SECTION C.D.

Fig. 15.

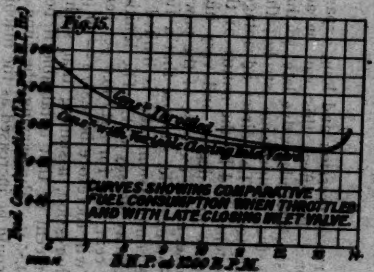
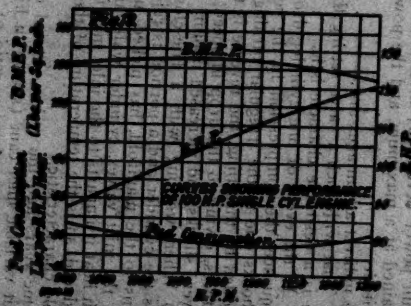
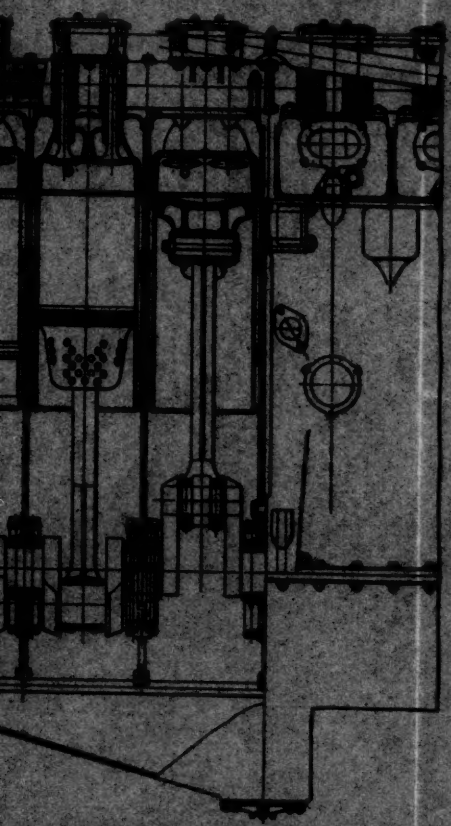
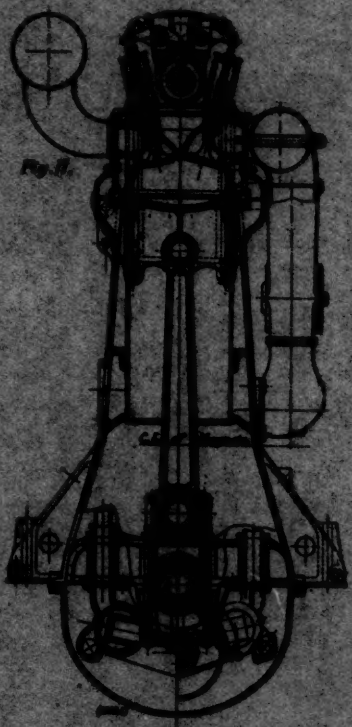


Fig. 2.







however, it became evident that this was unnecessary and undesirable, and manufacturers were urged to design their engines on the assumption that they would not be opened full out below 10,000 feet. So far as the writer is aware, no manufacturers actually produced such an engine. It is, however, interesting to consider what might be done in this direction. We will begin with the assumption that modern aviation spirit has a toluene value of 10, which is about the average value of American aviation spirit. At 10,000 feet the air density is 0.72, and at this density a compression ratio of 7.0:1 could be used with such a fuel, giving a theoretical limiting thermal efficiency of 38.8 per cent and a theoretical limiting mean pressure of approximately 165 pounds per square inch reckoned at ground level or 119 pounds per square inch at 10,000 feet. Under these conditions let us now consider what power the engine could develop at ground level, keeping just free from detonation. If controlled by throttling the maximum indicated mean pressure would be approximately 93 pounds per square inch. If controlled by varying the time of closing of the inlet valve it would be considerably higher, because for various reasons the efficiency obtainable under these conditions is greater and would be very nearly in the ratio of 5.25:7.0 × 165 (5.25 being the limiting ground level compression ratio for a fuel of toluene value 10) or say about 122 pounds per square inch. If controlled by the addition of cooled exhaust gas the mean effective pressure, as shown previously, would be very nearly equal to the full available M.E.P. with a compression ratio of 5.25:1 or 140 pounds per square inch.

In all cases let us assume that the mechanical losses of the engine are equivalent to an M.E.P. of 15 pounds (a fair average figure). Then the theoretical limiting brake mean pressure in the three cases would be:—

(1) 80 pounds per square inch.

(2) 107 pounds per square inch.

(3) 115 pounds per square inch, while at 10,000 feet the brake M.E.P. will be 104 pounds in all cases.

In all three cases the explosion pressure would be substantially the same, and little or no higher than at 10,000 feet—that is about 450 pounds to 500 pounds per square inch. In the latter case it will probably be actually lower, because the principal effect of the exhaust gas is to slow down the rate of burning and so round off the peak of the diagram. Assuming that the propeller torque varies as the square of the speed and directly as the density, then, if the engine is designd to run all out at 10,000 feet at 1,500 r.p.m., its maximum speeds at ground level will be approximately 1,100 r.p.m., 1,270 r.p.m., and 1,320 r.p.m., respectively. In the former case such an engine would probably fail to leave the ground. From these considerations it seems clear that the principle of designing a very high compression engine for use at high altitudes and throttling it on or near the ground is not the right one. Of the three methods considered, the use of exhaust products appears to be the most hopeful as a means of permitting a very high compression engine to operate satisfactorily at low altitudes, and still have sufficient power to get rapidly off the ground. The alternative method of dealing with the problem of varying atmospheric pressure is to maintain artificially ground level density in the cylinder at high altitudes by supercharging. From the point of view of engine weight there can be no doubt that this method scores heavily, for, although the strength and weight of many of the parts may be proportional to the density in the cylinder, there still remains a very considerable number whose weight is altogether independent of the pressure in the cylinder, so that the weight of the engine, as a whole, can only vary as the density plus a very large constant.

There are at least two possible ways of dealing with the supercharging problem, one by merely forcing more fuel and air into the cylinder by means of a pump or blower and the other by employing a supercharge of pure air in a stratified form. Some four years ago the writer carried out a very extensive series of tests on this latter system, and obtained most encouraging results on two experimental engines, but had to break off these experiments and concentrate all his attention on engines for tanks. The results obtained were, however, so encouraging that further tests should be made. Apart from the obvious increase in power at high altitudes this system of supercharging provides a perfect and automatic compensation of mixture strength for altitude, and gives a considerable increase in economy, the consumption falling from 0.49 pound per brake horsepower-hour when running normally to 0.455 pound when supercharging.

Limiting Size of Cylinder.—Designers of aircraft engines have, in the writer's opinion, shown quite unnecessary timidity in regard to the power output obtainable from individual cylinders. So far as the writer is aware no one has yet had the courage to construct an aero engine with cylinders developing more than 50 horsepower each. Some two and a half years ago, as a result of experience with large cylinders on tank engines, the writer was requested or rather challenged by the Air Board to design an engine for aircraft to develop 100 horsepower per cylinder. A complete design was prepared, and after much delay a single cylinder unit was built at Farnborough having a bore of 204 mm. and a stroke of 280 mm. A part longitudinal section and a cross-section of the complete six-cylinder 600 horsepower engine are shown in Figs. 16 and 17. This unit has been running on and off for over a year. Apart from a mysterious failure of the valve gear at first which has never been quite explained, it has given very little trouble, and no trouble at all which can be attributed to its large size. In view of the fact that its compression ratio is only 4.84:1, the results obtained are rather extraordinary and constitute, the writer believes, quite a record for so low a compression. From the accompanying curves, Fig. 18 (for permission to publish which the writer is indebted to the Superintendent of the Royal Aircraft Establishment), it will be observed that this single-cylinder unit develops 120 brake horsepower when running at 1,350 r.p.m. with a consumption of only 0.493 pound per brake horsepower-hour at its normal speed of 1,250 r.p.m., corresponding to an indicated thermal efficiency of 31.2 per cent, or within 4 per cent of the limiting value for this compression and an indicated mean pressure of 150 pounds per square inch. These results will, the writer hopes, help to dispose of the myth that very large cylinders can only operate with relatively low mean pressures and at a low efficiency.—"Engineering," January 7 and 14, 1921.

TECHNICAL RESULTS OF THE BATTLE OF JUTLAND.

By Salvatore Orlando.*

In the first period of the battle of Jutland six British ships fought. These were subsequently reduced to four, against five German vessels. The ships were the battle cruisers *Lion*, *Princess Royal*, *Queen Mary*, *Tiger*, *New Zealand*, and *Indefatigable*, and the *Lutzow*, *Derfflinger*, *Seydlitz*, *Von der Tann*, and *Moltke*. The other battle cruisers *Invincible*,

* Abstract of a paper read before the Genoa meeting of the Italian Society of Naval Architects and Marine Engineers, December 4 1920.

Indomitable and *Inflexible*, joined Admiral Beatty's squadron after the loss of the *Indefatigable* and *Queen Mary*. On both sides the types were the very best and newest produced by the naval technics and the national industry of the two countries in the matter of battle cruisers.

The oldest British units were the *Invincible*, *Indomitable* and *Inflexible*, launched in the spring of 1907, and the German *Van der Tann* launched in March, 1909; whilst the latest were on the British side, the *Tiger*, launched in the autumn of 1913, and the German *Lutzow*, launched on November 29 of the same year. It has been said that the battle of Jutland was mainly a big ship fight, and, in point of fact, the action of the light cruisers, destroyers and torpedo boats, which was lively during the fight and the following night, did not and could not have important results. I shall therefore limit my considerations to the battle cruisers the names of which I have stated above. The battle was fought by cruisers each propelled by Parson's turbines, with the exception of the *Tiger* which carried, for the high-pressure side Brown-Curtiss turbines. Steam was supplied, in the British ships, by Yarrow and Babcock-Wilcox boilers, and by Schulz boilers in the German units. None of the cruisers considered was fitted with reduction gear, this gear having made its appearance in connection with the cruising turbine of the *Queen Elizabeth* only.

Oil fuel firing was largely used in the British fleet and in the German destroyers, but only to a very limited extent in the large units of the latter nation. For this reason the German cruisers were not in a position to push steam production to the maximum allowed by the boilers and tubes. If it be taken as an extreme limit that 300 kg. of coal per square meter of grate area can be burnt in one hour, giving an evaporation of 2,400 kg. on replacing this by oil fuel, at a normal consumption of 7 kg. per square meter of heating surface and reckoning upon a heating surface 50 times greater than the grate area, with an evaporation of 11 kg. per kilo of oil burnt, the same boiler will yield 3,850 kg. of steam as against the 2,400 kg., or about one and a half times more. This explains why the British were able in the action to exceed with their ships the speeds secured at the speed trials, whilst the Germans remained below the results they had claimed, although the Schulz boiler, which is, in substance, a boiler adapted to torpedo boats and light ships, lends itself rather better to high combustions than the boilers in the British ships.

The maximum squadron speeds run at Jutland by the British cruisers were 28 knots, and 28.5 knots at the Dogger Bank, whilst those of the German cruisers never exceeded 26 knots. There was, therefore, a difference of at least 2 knots between the speeds of the two squadrons which had to develop their maximum speed in various phases of the action. It is difficult, not to say impossible, to indicate with technical exactness the secondary damage to machinery which occurred in the fight, it can however be said that in neither of the two squadrons did the sustained effort cause any, and that the squadron formations could be maintained, with the exception of those ships which were badly hit by artillery or torpedoes. Heavy damage to machinery makes it necessary for the damaged ship to be towed; following upon the Jutland battle only one cruiser was towed.

Under the heading "Damage caused by Artillery" the paper also deals more especially with the action in which the six British and five German cruisers above referred to took part, since it offers an easy comparative study. This action, which commenced at 3.48 (English time) on May 31, 1916, produced three minutes later its first artillery effects, when the *Lion* and the *Princess Royal* were struck. At 4 o'clock the ships were fully engaged on both sides; at 6 minutes past 4 the *Indefatigable*, repeatedly struck, retired and capsized. The six British ships accounted for a total

initial energy of 889,856 meter tons, the five German ships having 645,276 meter tons, this showing a superiority in favor of the British ships of 1.37 to 1, assuming that the rapidity of fire of one salvo per 30 seconds was equal.

The German ships were also inferior to the British as regards speed. Seeing that speed, according to competent tacticians and to simple common-sense deductions, is of primary, if not of vital importance, one is justified in taking as a criterion in this matter the square of the two speeds for purposes of comparison, this giving—

$$\frac{28.5^2}{26^2} = 1.20 : 1$$

But the German ships, as some compensation for the deficiency in offensive power of their heavy artillery and in speed, were provided with a system of armor protection superior to that of their opponents. It will suffice to mention that the maximum thickness at the sheerstrake was 305 mm. in the German ships and 228 mm. in the British, to say nothing of the superiority in quality and resistance of the steels used in the German fleet (Jellicoe, "The Grand Fleet"). The horizontal protection also, that is to say the measures taken to prevent the penetration of the decks by the projectiles of high angle fire and to keep the flames from exploding shells from spreading rapidly through the elevators and other means of communication, was also of marked superiority in the German cruisers. In the German ships, the lateral longitudinal bulkheads were protected by nickel steel armor running over a great part of the ship's length, whilst in the British ships the maximum protection was limited to those parts adjoining the munitions magazines.

An approximate measure of comparison for the protection of both squadrons may be arrived at by placing side by side the resistance to perforation of the maximum thickness of the vertical armor, and assuming that the same proportion obtains in the horizontal armor of the two squadrons, and neglecting the difference in the steel quality. Since it is generally admitted that resistance to perforation of steel plates is proportional to the square of their thickness, it follows that the ratio between the squares of the average thickness of the main armor covering of the opposing squadrons will give the comparative value of the protection, hence

$$\frac{\text{Value of the British defensive system}}{\text{Value of the German defensive system}} = \frac{211^2}{286.8^2} = 0.54$$

A very similar result is arrived at if instead of the maximum thickness of the armor the total weight of armor and protection is taken in the case of those ships for which these data are known.

There would, of course, be other elements to take into account to arrive at an exact relative value of the two squadrons. In the first place there are the available means for underwater offensive. But there could appear to be no necessity for taking this into account, for only the effects of gun fire between cruisers fighting always at a distance greater than the possible range of torpedoes is now being considered. In the same way, the consideration of the various conditions affecting the work of the crews, questions of habitability, of the spirit of decision on the part of the commanding officers, and of various other tactical features and fortuitous occurrences, do not enter into the technical study forming the object of the paper.

From an exclusively technical point of view an interesting comparison can be obtained by multiplying together the three factors given above. This

gives as the technical value of the British squadron $1.37 \times 1.20 \times 0.54 = 0.887$ of the German squadron. That is to say, the six British cruisers in the artillery encounter represented a technical war value of about nine-tenths that of the five German ones. This is a rough valuation, but it is not contradicted by the facts and appears to be shared by British public opinion which extols the valor of Admiral Beatty in having engaged the German cruisers with the intention of allowing the ships of the line to come into action though aware that he was running great risks with his own ships. This comparison is also justified by the fact that the three British cruisers *Indefatigable, Queen Mary* and *Invincible* were sunk by the German cruisers though the latter had up till that point suffered no loss, and that this was accomplished notwithstanding the manner in which the action was conducted by Admiral Beatty, which is considered by experts to have been most able. Further, at the close of the day, the five German ships found themselves unable to continue the fight, but this was due especially to the 381 mm. projectiles fired by the squadron of four fast battleships which acted in support of the cruisers, and to the projectiles of the Jellicoe squadron.

In the particular action dealt with between the two cruiser squadrons, the torpedo did not, for various reasons, play any decisive nor any very important part, notwithstanding the very large number of torpedoes launched. It appears that no torpedo launched from a battle cruiser struck an enemy cruiser. This, besides the distance which was maintained between the adversaries, was due to the impossibility of directing with any degree of accuracy torpedoes launched by transverse underwater tubes from ships steaming at a speed of 25 knots or 26 knots.

The action of the numerous submarines had more effect in attacking by torpedo and in driving back the enemy's flotilla of submarines. In this, secondary, action which has been vividly described by Captain van Hase a very large number of torpedoes were launched and two German ships, the *Seydlitz* and the *Lutzow* were struck and damaged, for, as Captain van Hase states, the British submarines managed to get "diabolically near" the enemy cruisers, notwithstanding the active firing of the secondary armament of the ships and of the submarines. It is evident that the submarines found it most advantageous to attack the bows of enemy ships, since the effect of the combination of the speed of the torpedo and of the ship, enabled the submarine to attack from distances greater than the normal range of torpedoes, whilst at the same time also being less exposed to gun fire; both the *Seydlitz* and the *Lutzow* were struck in the bows. But still more effective and more decisive was the night action of the submarines, especially on the part of the British. The scope of the present paper is, however, confined to the action between the cruisers and this is not the time to enter into those technical details. It may be added, at all events, that the secondary armament carried by the ships was also effective in keeping submarines at a distance.

In summing up the losses and damages on both sides with regard to the battle cruiser action, and including in the figures those for the lighter cruisers and the battleships which came into contact with the battle cruisers during the engagement, the losses covering the British *Indefatigable, Queen Mary, Invincible, Defence, Warrior, Black Prince, Nomad, Nestor* and *Shark*, a total of 107,435 tons, and the German *Lutzow, Wiesbaden*, and three destroyers, a total of 35,800 tons, these losses may be classed as shown in table on page 610.

There was, as will be seen, a great preponderance of losses by gun fire over those by torpedoes, a difference which is still greater when it is considered that the *Black Prince* and the *Wiesbaden* were placed *hors de*

combat and completely disabled before being torpedoed. In the day engagement, only a single action, that against the *Marlborough* was decidedly in favor of submarine offensive. The great distance between the units, the difficulty of underwater launching and the high squadron speed have already been mentioned in regard to torpedo attack. The torpedoes which reached their targets may all be taken as having been launched by light ships, and in this respect the British squadron showed itself superior to the German.

	British.		German.		Total.	
	No.	Displacement.	No.	Displacement.	No.	Displacement.
By gunfire	7	92,950	3	2,800	10	95,570
By torpedoes ..	2	14,485	2	33,000	4	47,485

If in addition to the ships above referred to the damage by gun fire and torpedoes to other ships which, at the close of the day, could be taken as disabled, were included, there would come in on the one side the *Marlborough* and, on the other, the *Seydlitz* and the *Derfflinger*, the two latter having been disabled and their guns silenced; to include these might, however, give rise to uncertainties and they have therefore been omitted. The proportion between the ships lost by torpedoes and by gun fire would again vary, the German losses by torpedoes increasing, if account were taken of the vessels sunk during the night which followed the battle. In this case there would have to be reckoned Germany's loss of the old battleship *Pommern* of 13,000 tons, torpedoed and exploded early in the morning of June 1; of the light cruiser *Rostock* of 4,800 tons, also torpedoed; of the *Frauenlob*, 2,600 tons, sunk by gun fire; of the *Elbing*, another light cruiser sunk in action against British destroyers, and other five destroyers. In the same night, the British squadron lost the *Sparrowhawk*, *Tipperary*, and *Turbulent*, the former by an accidental collision, the other two sunk by German ships, and also the *Fortune* and *Ardent*, of 900 tons, sunk by gun fire.

Examination of the night losses, however, does not help to establish any comparison between the effects of gun fire and of the torpedo, the actions having been intermittent and the occurrences frequently accidental. It is evident that in the Jutland battle, as is now generally admitted, the heavy armament on both sides came chiefly into play, the torpedo taking but a very minor part in the action. Aerial craft played no part beyond reconnoitering carried out by a British aeroplane and by a German dirigible.

The engagement proves the great utility of adequate armor protection, this requisite having enabled the Germans to inflict damages far in excess of those they suffered. In this connection it may be said that a comparative study of the quality of the steels used by the two fleets both for armor and projectiles will throw much light upon the great event which has signalized the end of the German naval power. Admiral Jellicoe and, in general British technical men admit the superiority of the German materials, specially the high explosive projectiles at long ranges, the armor piercing shells fitted with a fuze with delay action at short ranges. It cannot be

denied that a careful preparation relying not upon naval traditions but upon unwearied study on the part of technical men had at the Jutland battles the foreseen consequences.

The effectiveness of the means of defense against submarine explosions has to be placed to the credit of the naval architects of the two nations. The most efficient means of defence was that of the transverse watertight bulkhead, since all the torpedoed German ships which could make port were able to do so because one transverse bulkhead at least resisted the water pressure of the thrust upon it due to the speed of the ship. The battleship *Audacious* which struck a mine in October, 1914, off the coast of Ireland and had a hole 10 m. long blown in her hull only sunk close to port and then solely owing to the bad weather prevailing at the time. The *Marlborough* retired from the line five hours after being torpedoed, the watertight bulkhead which kept her afloat being unable to withstand the heavy pressure upon it caused by her speed of 17 knots which was that required to maintain her in the line. The *Seydlitz* was also able to save herself because her transverse bulkheads held.

It is therefore particularly upon the transverse bulkheads, their distribution, strength and height, that the studies of naval architecture will have to bear in future, and this with all the greater reason because the submarine peril remains a most serious one. In the engagement under review the British Navy lost only two units by submarine action, whilst during the whole war of a total of 213 units lost, 93 were sunk by submarine explosions. If we consider the case of Italy fighting in the Adriatic, a sea of no great depth, in which mines can easily be laid and where the action by submarines and torpedoes is also easy owing to the proximity of the bases, we have to guard against danger in this direction with the greatest care. During the war, our losses by torpedo or mine amounted to about 52 per cent of the total. For the same reason, all the important losses inflicted by Italy upon Austria were due to mines or the torpedo.

In the future, the transverse section of the armored deck will have to be modified with the object of decreasing the volume of the lateral, flooded compartments and facilitating the dispersion outside the ship of the gases from explosions which now reach the inside. At Jutland the armored deck answered its purpose in regard to protecting the engines, boilers and steering gear. It was perforated in the case of two German ships and probably in that of a British one, but generally speaking it remained watertight. As much cannot be said in regard to the protection of the ships' stability which the shape of the cross section was intended to insure. The ships sunk both at Jutland and at the Dogger Bank either blew up owing to fire in the magazines or capsized. Almost in every case, the central line of the armored deck, when the ships were cleared for action, was level with the plane of flotation or below it, this rendering the trapezodial section useless with regard to stability.

Given the probability of great developments in the future of aerial attacks with projectiles falling at angles of 45 degrees, with the same incidence both on the sides and on the deck, it will be in future unreasonable for the naval architect to design ships so that a target 30 m. wide is presented by the deck, and a target of only 5 m. in width, by the sides, both exposed to the same danger but the first being protected by a 25 mm. thickness of steel, whilst the other is protected by a thickness of 300 mm. This was the state of matters at Jutland and it had its fatal consequences. The whale-backed shape appears to be the solution, the deck armor being continued to the sides. The problem of deck armor, which is difficult for reasons of displacement and stability, will probably tend to the production of ships having fewer guns, and comparatively low in the water, with a

small ratio of length to breadth, the latter feature enabling them to be easily maneuvered against torpedo attack. The extreme lateral positions of the main installations was found at the Jutland battle to involve grave danger. The same may be said of the location of the munitions magazines in the center of the ship between the stokeholds; this must be done away with as also side underwater torpedo launching tubes, since these were found to be useless at the high speeds which prevailed.

In regard to boilers, those having small tubes and using oil fuel showed their superiority. The necessity was also demonstrated of keeping the feed water tanks low down so as to prevent what happened to the *Lion* at the Dogger Bank. The oil fuel reserves have to be kept low down also so as to decrease fire risks. Radical reforms will also have to be made in connection with all stores containing combustible material and exposed to shell fire, as also in the means of communications between magazines and guns.

There is no evidence that there were present at the Jutland battle any ships provided with automatic stabilizing devices, but it is known that especially in the German navy there was in this connection very efficient organization. Considering the enormous volumes of water which entered the ships struck by torpedo, automatic systems would appear to be impossible. The operation of stabilizing would have to be very prompt and quick in action, for this is essential to the saving of a ship, but the effect will have to be secured by valves operated at will. The introduction of anti-rolling tanks seems to be excluded also. The course of the two squadrons, especially that of Captain von Hase, involved many changes and evolutions, and in such conditions the anti-rolling tanks would be the source of grave danger in a rough sea.

Concluding this rapid review, made exclusively from the naval architect's point of view, it may be said that whilst from a consideration of the Jutland battle alone, speed, gun fire, and armor protection appear to be pre-eminent in importance above all other factors, such views must be modified to suit the various conditions of different seas where future naval engagements may take place; the future development of aerial craft has also to be borne in mind. If one considered only the Jutland battle, ships powerfully armed, heavily armored, of very high speed and of very high cost would be suggested. If on the other hand one looks at the war at sea as a whole, one realizes that the mine, the torpedo, the submarine and the torpedo boats, even of the smallest classes, have actually played a much greater part.—"Engineering," January 14, 1921.

EXPERIMENTS ON THE OSCILLATION OF OTTERS.

By Robt. F. McKay, M.Sc., A.M., Inst. C.E.

The paravane is a highly successful invention developed during the war to combat the submarine menace and to protect ships against moored mines. When fitted to merchant shipping, the device went by the name of otter, and was used only to protect the ship against moored mines. The appearance and utility of the paravane or otter have already been described in the paper presented by the author to the British Association in 1919.

The experiments upon which the results given in this article are based were conducted upon otters of the type known as M II. at the Vickers Testing Station at Weymouth. It should be explained that otters were manufactured by different sub-contractors and despatched to Weymouth or Milford Haven, where they were tested by Messrs. Vickers in the presence of Board of Trade officials acting under Admiralty directions. After

passing the prescribed test, they were accepted by the Admiralty and despatched to the different ports of installation.

It is not desired in this article to enter fully upon the utility of otters or to discuss the theory of their running. It is concerned chiefly with the running of otters under testing conditions. Test conditions are different from the ordinary running conditions in one important particular, viz., the otter is towed from a point above sea level during test. As a matter of fact the otter was set to run at a depth of 20 feet, and was towed at a maximum speed of 16 knots tested from the stern of a torpedo boat by means of a towing wire 45 yards in length.

An otter of the M II. type may fail during test for any one of four reasons, viz.:—

(*a*) The otter may be non-buoyant;
(*b*) The otter may not dive at low speeds;
(*c*) The otter may not run at the set depth; and
(*d*) The otter may oscillate more than a specified amount.

As regards the first two points, the testing officer observed the behavior of the otter at the commencement and conclusion of the run. As regards the third and fourth points, the method of judging the depth and oscillation of an otter was by noting the length of the towing wire between the surface of the sea and the tow point on the vessel during the run. The ship end of the towing wire was marked off in fathom lengths, and with each fathom length was associated a depth. The behavior of the otter could then be quickly observed during the run.

The distinctive difference between the port and starboard towing wires during the run is that the port wire enters the water at a much steeper angle than the starboard wire, even though the otters are running at the same depth. This is due to the turning effect on the wire caused by the water resistance when towing a right-hand lay wire through the water on different quarters of the vessel. This effect will be termed for brevity the "turbining effect." It was not possible to perform tests on wires at Weymouth to elucidate further this interesting phenomenon, which will therefore not be considered in detail. In order to allow for the weight of the wire and the turbining effect of towing a right-hand lay wire through the water, it was assumed that the port wire sagged 4 degrees, and that the starboard wire hogged 2 degrees. Tables of depth readings were then drawn up, giving the depth of otter corresponding to the length of wire visible between the point of tow and the surface of the sea.

Of the otters which failed to pass the test, it was found that 95 to 98 per cent were starboard otters, and they failed because of excessive oscillation. It was found that, generally speaking, port otters ran steadily. Indeed, many failed starboard otters passed successfully when transferred to port. Examination of failed otters showed that the known reasons for the oscillation of otters, viz., incorrect alignment, defective workmanship, excessive friction in the moving parts of the hydrostatic valve and rudder, did not in all cases account for repeated failures.

It is clear that the main difference in the running of starboard and port otters, all other things being the same, lies in the use of the towing wire with right-hand lay on both sides of the vessel. All trouble would be removed by the use of a right-hand lay wire on the port side and a left-hand lay wire on the starboard side. However, if adopted for testing purposes, this arrangement would also have to be adopted for service conditions. This was deemed inadvisable because of the presumed difficulty an ordinary deckhand on a merchant vessel would have in distinguishing between

a right-hand and left-hand lay wire, and because of the extreme likelihood of many mistakes occurring. There would be the further disadvantage that an increased number of spare parts would have to be provided. It was therefore necessary to stabilize the starboard otter in another way.

It occurred to the author that the turbining effect of the wire caused a couple of different hand and a force of different direction to act upon port and starboard otters, and that therefore a solution to the problem of the failed starboard otters would be obtained by making the trim of the starboard otter different to that of the port. As a few tentative experiments proved that there was some truth in the suggestion, the author was instructed to conduct experiments to obtain further information.

The only piece of extra experimental apparatus designed for the work was a special towing bracket. This towing bracket replaced the cutter bracket on certain runs, and was such that the point of tow could be moved relatively to the plane. It was thus possible to conduct experiments to show the effects upon oscillation when the tow point of the otter was altered either longitudinally or transversely.

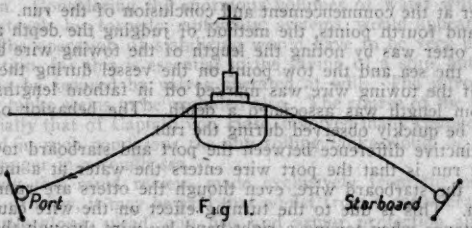


Fig. 1.

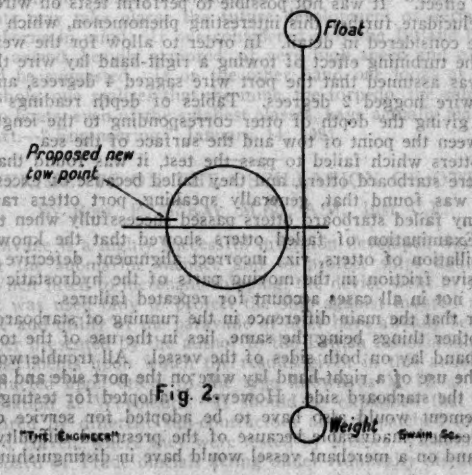


Fig. 2.

The idea of experimenting upon the transverse position of the tow point occurred to the author from the following considerations:—Fig. 1 shows that under testing conditions, the plane of the starboard otter is probably further from the vertical than the plane of the port otter. Although the difference between the two angles is computed to be only about 6 degrees, the effect is greater under testing conditions than under service conditions, when the ropes are, neglecting hog and sag, approximately horizontal. At any rate, the starboard plane could be made to approach a vertical position by altering the tow point from the center line of the otter to a position nearer to the float—as shown in Fig. 2. By suitably selecting this position, it was thought that the starboard otters would prove as stable as port otters under testing conditions. Unfortunately, it was not possible to throw the tow point eccentrically more than ¼ inch with the apparatus at the author's disposal.

Four otters were chosen for experimental purposes. It was known that when the otters came from the manufacturers they varied very considerably in weight and balance. The preliminary investigation of each experimental otter consisted of:—

(*a*) Examination of alignment;
(*b*) Determination of weight and center of gravity; and
(*c*) Determination of buoyancy and center of buoyancy.

The experiments carried out may be summarized under the following headings:—

(1) Effect of altering longitudinal C.G. of otter; (*a*) weight of otter constant; (*b*) weight of otter variable.
(2) Effect of altering transverse C.G. of otter.
(3) Effect of altering setting of helm.
(4) Effect of altering point of tow longitudinally.
(5) Effect of altering point of tow transversely.

It was impracticable to arrange the experiments on a purely scientific basis. On account of the many variables it was not possible, for example, to arrange consecutive experimental runs in which only one factor was altered at a time. A special design of otter would have obviated this drawback, but the urgency of otter manufacturing work at the time made this course impossible. Time being important, the experiments had to be conducted upon otters of normal design. The experiments were therefore arranged to be such as to provide quickly such information as would facilitate the design and successful testing of otters. And in particular, the commercial stabilization of the starboard otter was of primary importance. In other words, it was desired in these experiments to determine some method or methods of reducing the oscillation of the starboard otter with as little modification as possible of the manufactured stock of otter component parts.

The results of the experiments may be briefly summarized as follows:—

(1) Although a large proportion—from testing station records, about 95 per cent—of starboard otters are normal in their behavior, it would appear that some change of trim would facilitate the passing of the remainder.

(2) Effect of trim on port otters is seen chiefly on diving. Tail-heavy otters, *i.e.*, otters whose C.G. lies aft of the normal position, dive slowly to working depth; head-heavy otters, *i.e.*, otters whose C.G. lies forward of the normal position, dive too quickly at the commencement of the run and tend to strike bottom. There appear to be wide limits for the position of the C. G. of port otters within which successful running will occur.

(3) Changes of running depth, due to alterations of trim within the passing limits, are not constant. This may be due either to errors in the reading of the fathom marks on the towing wires or to a slight variability in the stiffness of the diaphragm. On the whole, it would appear that the movement of the C.G. forward makes the otter run slightly more shallow; the movement of the C.G. aft makes it run slightly deeper than the set depth.

(4) No relation between the movement of the transverse C.G. and the passing or failure of an otter can be found, although the evidence on this point is not conclusive. It would appear that the position of the transverse C.G. only affects the otter in diving or at very low speeds. The larger dynamic forces on the plane when running at the higher speeds seem to wash out any little alterations that can be made to the static transverse C.G.

(5) It would appear that small changes in the weight of an otter, that is in effect, changes in the reserve buoyancy of an otter, do not affect appreciably the running. Otters may, however, be too heavy or too light. They are too heavy and fail by specification if they do not rise to the surface at the conclusion of the run. That is to say, the reserve buoyancy of an M II. otter must be such that it can float whilst carrying about one-half of the weight of the towing wire. As regards the running test, however, it would appear that heavy otters run very steadily, and that the upper limit for the weight of an otter was not reached on these experiments. In fact, it would appear that the specified condition that otters should be buoyant at the conclusion of the run is only laid down because of the practical difficulties of seamanship when the otters are used on service.

On the other hand, there appears to be a limiting value to the minimum weight of an otter. Below this weight the otter appears to be unstable when running. The reserve buoyancy of an otter is apparently overcome by the rudder; that is to say, the rudder is not exactly neutral when the otter is running at its set depth. And the greater the reserve buoyancy the greater must be the movement of the rudder from its neutral position. Apparently, an excessive rudder angle to overcome buoyancy is sufficient to alter the virtual trim, and in that way to cause oscillation.

The turbining effect of the wire reduces the virtual buoyancy of the port otter, but increases that of the starboard otter by an amount which varies as the speed of tow. Otters therefore tend to be unstable on the port side at the commencement of a run when the turbining effect is small, and unstable on the starboard side at full speed when the turbining effect is a maximum. The results of experiments seem to confirm these theoretical conclusions.

(6) Otters changed from port to starboard or from starboard to port do not run at the same depth for identical trims. The otters appear to run deeper on the port side. This is partly due to errors in the tables of running depths—particularly the table for port running—and partly to errors in alignment.

(7) Effect of "up" or "down" helm is not only to alter the running depth of the otter, but often to change the amount of oscillation also. This latter effect is probably partly due to some stiffness in the diaphragm or to the diaphragm not being originally set neutral.

(8) The effect of the unbalanced towing resistance of the tail weight does not appear to be appreciable.

(9) The position of the tow point longitudinally could with advantage be moved from its present position.

(10) The position of the tow point transversely could with advantage be placed nearer the float in starboard otters. The results of the experiments on the port otters were not concluded because they interfered with the output of tested otters from the station. It appeared, however, that little advantage accrued from any alteration tried. These results are in accordance with the theory enunciated earlier in this article.

In conclusion, the author wishes to acknowledge his indebtedness to Vickers Limited for the opportunities afforded him of prosecuting this research and for the permission kindly given of publishing this article.—"The Engineer," July 1, 1921.

FLOATING DRY DOCK FOR TESTING SUBMARINES.*

By Von Klitzing.

In 1916 construction was begun in Germany on a floating dry dock for testing submarines and during the summer of 1918 the dock was completed. By means of this dock submarines can be tested under pressures corresponding to a depth of 264 feet without the necessity of risking the loss of lives or vessel. In 1919, under the terms of the Armistice, the dock was turned over to the British Navy and is now being used for testing British submarines.

The dock consists of a steel cylinder for testing submarines supported on pontoons with sufficient space on either side for docking a submarine for repairs. Pontoon "*a*" (Fig. 1.) has sufficient buoyancy to support the weight of the dock, the cylinder, and the submarines to be tested or repaired. The wing tanks "*b*" and "*c*" at the four corners of the dock serve to keep the dock on an even keel while being raised or submerged. The connecting tanks "*e*" and "*f*" provide stability when the dock is submerged, the submarines being tested with the dock partially submerged.

TESTING CYLINDER.

The testing cylinder has a clear diameter of 39 feet 5 inches and a length of 380 feet 7 inches. One end is closed by a hemispherical bulkhead and the other end is open. The open end is fitted with a steel ring sheathed with hardwood. The cylinder is built up of steel plates with steel stiffening rings spaced 39.37 inches. All seams and butts are treble riveted and all rivets are countersunk on the inside of the cylinder. Three domes are fitted at the top of the cylinder, one in the center and one at each end, for collecting the air which is expelled when the cylinder is filled with water. Air pipes lead from these domes to the control house where they can be closed by means of cocks as soon as the cylinder is full. The middle dome is fitted with a safety valve. Access to the submarine to be tested is provided by a trunk (Fig. 2). Three manholes are fitted for access to the interior of the cylinder. Four large electrically operated slide valves provide for rapid drainage of the cylinder.

CAISSON FOR CLOSING THE CYLINDER.

The caisson for closing the open end of the cylinder consists of a floating vessel whose periphery is elliptical. One side of the caisson is spherically shaped and the other side is shaped like the frustum of a cone (Fig. 3). The spherical side takes the pressure while the other side is so

* From "Zeitschrift des Vereines Deutscher Ingenieure."

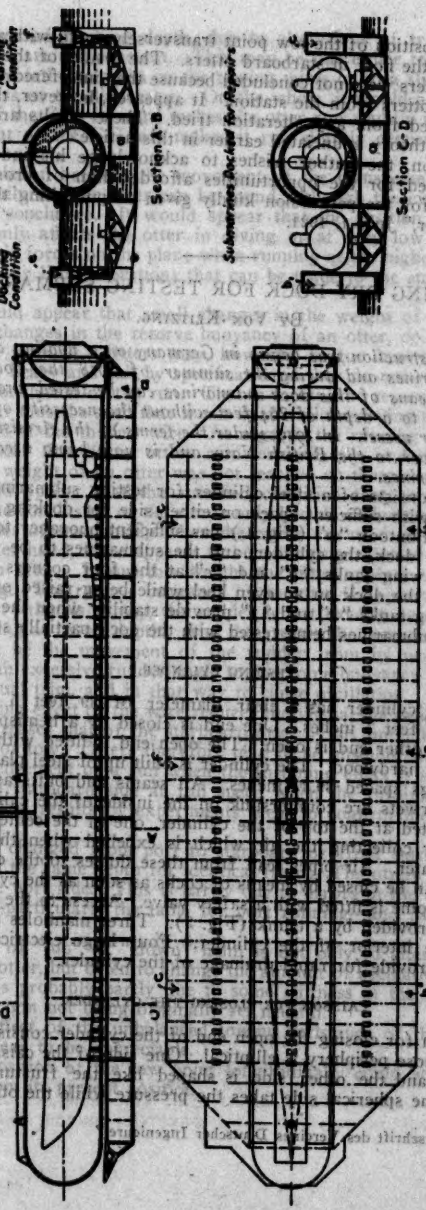


Fig. 1.—General Arrangement of Floating Dry Dock for Testing Submarines

formed as to give the proper stability to the caisson when floating. At the periphery of the caisson a steel surface is provided which lies against the wood sheathing of the steel ring at the end of the cylinder.

When pumping water into the cylinder, the pressure on the inside forces the caisson against the cylinder ring and thus prevents leakage. A counterweight, which can be rotated, is mounted inside the caisson. By means of a hand gear this weight can be rotated so that the caisson is turned through an angle of 90 degrees. It is necessary to turn the caisson through 90 degrees in order to get it through the similarly shaped elliptical open-

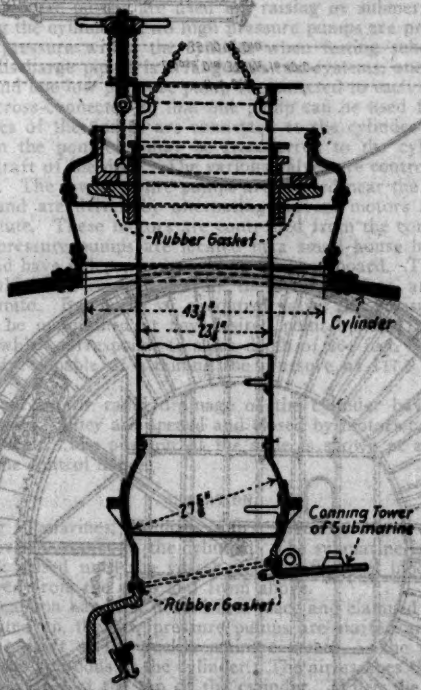
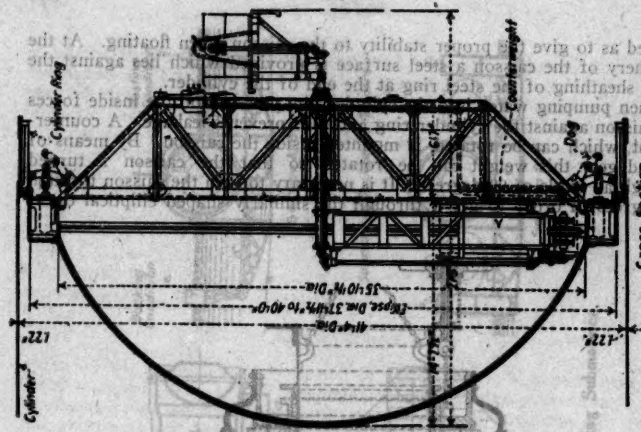
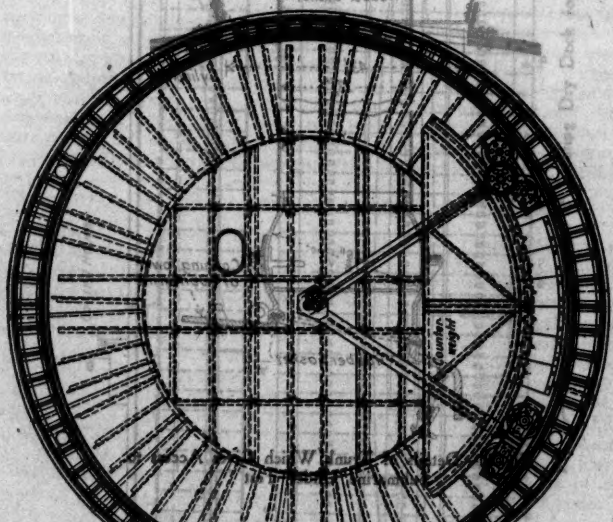


Fig. 2.—Details of Trunk Which Gives Access to Submarine Under Test

ing of the cylinder. After the caisson has been brought into the cylinder it is returned to the upright position and brought against the cylinder ring so that the flanges are in contact all the way around. It is held in this position by dogs at the outside of the cylinder and pumping then begins. The caisson is divided into watertight compartments which are emptied or filled with water in order to regulate its floating position.





Section in Way of Counterweight

Fig. 3.—Sections of Caisson

A roomy control house is located over the middle of the cylinder and contains all the apparatus necessary for raising or submerging and for testing the submarines. The apparatus is similar to that in use on modern floating dry docks and includes levers for the operation of the valves, draft gages for the different tanks and for the fore and aft drafts of the dock, hydraulic depth gages, and switches for the operation of the high and low pressure pumps and of the large slide valves for draining the cylinder.

PUMPING ARRANGEMENT.

Two low pressure pumps are used for raising or submerging the dock and for filling the cylinder. Two high pressure pumps are provided for increasing the pressure within the cylinder when testing submarines. The suction and discharge piping is arranged in two systems, one for each side of the dock and one low pressure pump is connected to each system. These systems are cross-connected so that one pump can be used for both. The discharge sides of the pumps are connected to the cylinder so that water pumped from the pontoons may be transferred to the cylinder without altering the draft of the dock. The various valves are controlled by means of rope pulls. The low pressure pumps are located near the bottom of the wing tanks and are driven by alternating current motors at 750 revolutions per minute. These motors are controlled from the control house.

The high pressure pumps are located in a small house beside the control house and have independent suctions from outboard. They are driven by motors, which are controlled from the control house, at 3,000 revolutions per minute. By means of a control valve, the pressure within the cylinder can be maintained at any desired point up to 117.5 pounds per square inch, which corresponds to a sea depth of 264 feet. The high pressure pumps are capable of attaining the pressure of 117.5 pounds in ten minutes.

The slide valves for rapid drainage of the cylinder have a 39.37-inch diameter opening. They are opened and closed by motors controlled from the control house. The position of the slide is shown at all times by an indicator in the control house.

OPERATION.

For testing submarines, the dock is first submerged to a depth of about 40 inches above the center of the cylinder. The submarine is then towed in and the dock raised until the vessel rests on the keel blocks. Then the vessel is stayed from the sides and from above.

When the caisson has been floated into place and clamped and the access trunk connected up, the low pressure pumps are started and the cylinder is filled. The draft of the dock remains constant, as the water is transferred from the pontoons to the cylinder. The air escapes through floating valves in the domes at the top of the cylinder. When the water reaches the domes, the valves automatically close and the air which remains can escape only through the air pipes leading from the top of the dome to the control house. When the cylinder is completely filled water escapes through the air tubes in the control house. The tubes are then closed, the low pressure pumps stopped, and the high pressure pumps run until the desired pressure is obtained.

If submarines are to be docked for repairs on either side of the cylinder, the operations are like those of a floating dry dock. It is not necessary to have a vessel on each side of the dock, an even keel being maintained by water ballast.

When the dock was put in commission by the German Navy, tests were run on it with the following results: The time required for filling the cylinder was one hour and forty-two minutes; seven minutes were required to raise the pressure to 117.5 pounds; and six minutes were required to reduce the water level within the cylinder to the center of the cylinder. —"Marine Engineering," June, 1921.

THE STRENGTH OF SUBMARINE VESSELS.*

By Mr. W. R. G. Whiting, M.B.E., M.A., Member.

The problem of the strength of submarines when submerged is, for the present at any rate, of historic rather than practical importance. But the professional interest of the subject is considerable and may afford some justification for presenting this paper. Originally planned when the cessation of submarine building seemed distant, it appeared desirable to trace the broad effect of variations both in shape and in disposition of structure. Such an investigation throws a much-needed light on the relative merits of structural arrangements. In order to obtain the quantitative data so indispensable in the early stages of a design, a fairly complete analysis of elliptical forms has been worked out. The methods adopted are in part an application of the principles enunciated in Professor Marbec's elegant contribution to the Transactions of 1911, but several of the results are believed to be original.

The problem presents features somewhat unusual in naval architecture, in that the system of loads to be provided for is definite, and is applied as frequently as trial or service conditions require. The divergence in these respects from the loadings due to wave action or to flooding on the longitudinal or the transverse structure of surface vessels need not be enlarged upon. For such vessels, however, the stresses set up by a conventional wave loading are known with an approach to accuracy which submarine strength calculations can scarcely equal. In most existing submarines the bulk of the material is in compression, and this involves the same difficulties, though in an enhanced degree, as arise in the theory of struts. Since the hydrostatic pressure on every point of a submerged vessel varies as the depth of the point from the surface, the pressures on any section do not maintain a constant proportionality between themselves as the depth increases. For considerable depths and small hull diameters this ratio approximates to unity, and it is customary to substitute for the real pressure a uniform one corresponding to the depth of the axis. The validity of this approximation becomes worth attention as lower factors of safety and increased dimensions are accepted. Since the external pressures act normally on every part of the surface, the material composing any transverse section must withstand the system of forces acting in its own plane and also the longitudinal components of all the forces acting between one extremity of the vessel and that section. The reaction to the longitudinal forces can be supplied only by the fore and aft structure of the vessel, commonly the plating alone. The compressive stresses that arise, though considerable, are of inferior importance compared to the transverse stresses, and will not be referred to hereafter, save in the Appendix.

Surface Conditions.—If we take a circular section of uniform scantling just floating in water (*i.e.*, with the water surface tangent to the uppermost point) it appears at first sight that it would experience a tendency to distort, owing to the variation of water pressure from zero at the top to a maximum value at the bottom. It will be shown, however, that this is not so, but that the bending moments vanish at all points of the circumference.

Consider in the first place a circular quadrant just awash (Fig. 1). The analytical proof that in this case the bending moment vanishes everywhere is given in the Appendix, and it is shown that the only resultant force at any point is a tangential thrust or hoop compression of the value $\sin\theta . R^2/2$. But if this

* Paper read at the Institution of Naval Architects, March 16, 1921.

value be assumed the equilibrium conditions of an element are such that the applied forces, when resolved by elementary methods, suffice to change the direction of the hoop compression C by the subtended angle $\delta\theta$ and to add an increment δC to this tangential force, which satisfies the terminal conditions. The thickness of the section has been taken as unit length and the forces are measured in unit length cube of the liquid.

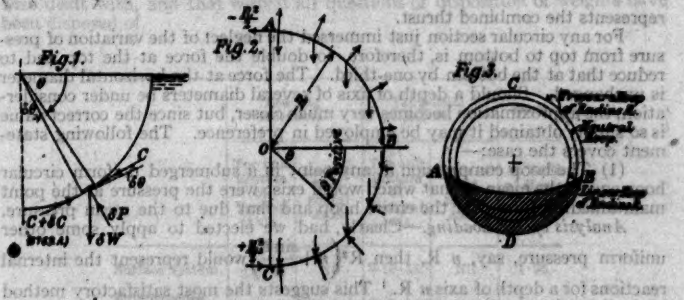
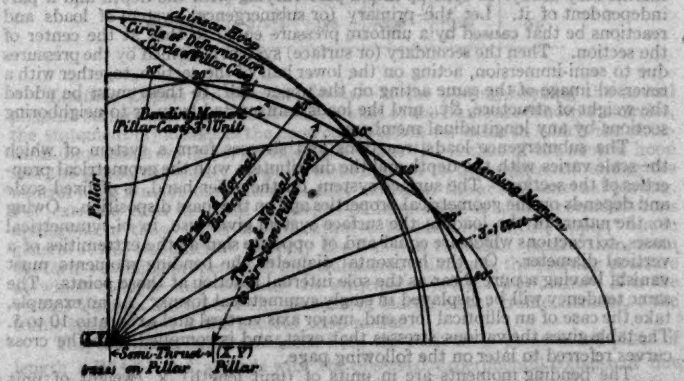


Fig.4. ELLIPSE 10:7 AXES RATIO, UNIFORM SCANTLING, WITHOUT & WITH PILLAR ON MINOR AXIS.



Apart from movement of a second order of small quantities, the section may be considered as undeformed. The reaction at the bottom is horizontal and of magnitude $R^2/2$, whilst at the top it vanishes. Now, imagine all the applied forces reversed in direction, so that the gravity forces act upwards and the hydrostatic forces act outwards. Equilibrium will be maintained, but the hoop compression becomes a hoop tension at all points. Let this quadrant be now revolved about the surface diameter and superposed on the original quadrant (Fig. 2). All gravity forces are now acting downwards, but negative hydrostatic forces act on the upper quadrant, the hoop compression decreasing from an intensity $-R^2/2$ to zero as one advances from A to B. A tension at A and an equal compression at C balance the whole of the applied forces. Provided angles measured above OB are treated as negative, the expression $\sin\theta . R^2/2$ continues to represent the hoop thrust everywhere.

Finally, subject the semicircle to a uniform hydrostatic pressure R. The combined head now vanishes at A, increases to R at B, and to 2 R at C. In fact, we have reproduced the condition of a circular-sectioned vessel just immersed. Due to the uniform pressure R we have added a hoop compression R^2 at all points, which, being added to the existing thrusts and tensions, produces a thrust $R^2/2$ at A, R^2 at B, and $3/2.R^2$ at C. At any point $R^2\left(1+\frac{\sin\theta}{2}\right)$ represents the combined thrust.

For any circular section just immersed the neglect of the variation of pressure from top to bottom is, therefore, to double the force at the top and to reduce that at the bottom by one-third. The force at the horizontal diameter is unchanged. Should a depth of axis of several diameters be under consideration, the approximation becomes very much closer, but since the correct value is so simply obtained it may be employed in preference. The following statement covers the case:—

(1) The hoop compression at any point in a submerged uniform circular hoop equals the mean of that which would exist were the pressure at the point maintained uniform over the entire hoop and that due to the mean pressure.

Analysis of the Loading.—Clearly, had we elected to apply some other uniform pressure, say, n R, then $R^2\left(n+\frac{\sin\theta}{2}\right)$ would represent the internal reactions for a depth of axis n R. This suggests the most satisfactory method of dealing with the general case, since the loading on any section of a submarine may always be split up into a part varying with the depth and a part independent of it. Let the primary (or submergence) system of loads and reactions be that caused by a uniform pressure equal to that at the center of the section. Then the secondary (or surface) system is formed by the pressures due to semi-immersion, acting on the lower half of the section, together with a reversed image of the same acting on the upper half; to these must be added the weight of structure, &c., and the loads transmitted from or to neighboring sections by any longitudinal members.

The submergence loads, reactions and stresses form a system of which the scale varies with the depth and the distribution with the geometrical properties of the section. The surface system, on the other hand, is of fixed scale and depends on the geometrical properties and on the mass disposition. Owing to the nature of the loading the surface system gives rise, in bi-symmetrical cases, to reactions which are equal and of opposite sign at the extremities of a vertical diameter. On the horizontal diameter the bending moments must vanish, leaving a pure shear as the sole internal reaction at those points. The same tendency will be displayed in singly symmetrical forms. As an example, take the case of an elliptical fore end, major axis vertical and axes ratio 10 to 5. The table gives the various stresses that exist, and is compiled from the cross curves referred to later on the following page.

The bending moments are in units of (unit length) × (weight of unit length cube); forces are in terms of weight of unit length cube. The major axis is taken as 10 units length; the depths, as defined above, are those of the center of figure below the surface and the weight disposition is uniform and equal to the displacement. Adding the figures for the surface and any selected submergence condition, the actual internal reactions become known. It is seen that for any considerable depth the submergence system taken alone forms an excellent first approximation, especially to the bending moments. It is also a legitimate one, since the surface system as herein defined gives rise to equal positive and negative departures from it.

Cross curves for all ellipses, placed with major axis horizontal or vertical are given in Figs. 8 and 9. A semigraphical method of calculating the surface system was utilized for these calculations, and when particular cases require this evaluation, it will probably be found accurate enough for the purpose and

* Paper read at the Institution of Naval Architects, March 19, 1903.

less laborious than a wholly analytical method. Further, the disposition of weights, which frequently includes ballast water or oil, is not invariable, but no possible variations of this nature, or even of the structural material, are likely to so affect the surface system as to cause any important effect on the combined system at considerable depths. It will be assumed when desirable in what follows that the surface system has been directly calculated or otherwise dealt with, and that with it all questions of disposition of weights have been disposed of.

	Bending Moments.		Tangential Forces.		Shear.
	Top and Bottom of Vertical Axis.	Ends of Horizontal Axis.	Top and Bottom of Vertical Axis.	Ends of Horizontal Axis.	At Ends of Horizontal Axis.
Surface system	$\pm 4 \cdot 53$	Nil	$\mp 10 \cdot 55$	Nil	$1 \cdot 05$
Submergence system—					
$d = 5$ ..	$-27 \cdot 25$	$+19 \cdot 5$	$+25$	$+12 \cdot 5$	Nil
$d = 50$ ..	$-272 \cdot 5$	$+195$	$+250$	$+125$	Nil

Limiting Depths for Circular Forms.—If the plating forming the actual pressure surface and the locus of neutral axes of the frame are concentric circles, the statement (1) measures the hoop compression for cases in which the structural dimensions are finite, provided the radius (R) is that of the neutral hoop and the pressure intensity assumed to be applied to the surface containing the neutral hoop is made equivalent to that acting on the actual external plating. For extreme cases in which the depth of immersion is small, considerations analogous to those for critical distributed loads on long struts apply,* but in general it will be sufficient to apply the Eulerian formula. Apart, then, from the form-retaining properties of any transverse bulkheads, the limiting pressure at which collapse may certainly be anticipated is $3 E I / s R^3$, where E is the virtual Young's Modulus, I the moment of inertia of the frame element, s the frame spacing, and R the neutral hoop radius.

This expression may be deduced from the limit for a pivot-ended pillar of length $\pi R/\sqrt{3}$ and accords with the observed experimental collapse of flue tubes to an equi-angular triangular form.† It follows that:—

(2) If the longitudinal element is kept constant, equivalent pressures vary inversely as the cube of the radii.

(3) If all linear dimensions are varied in the same ratio, the equivalent pressures are identical, and hence

(4) For equal depths the weight of structure varies as the submerged displacement.

Imperfections of workmanship, lapped seams and the secondary bending moments, due to the above assumption of concentricity not being fully realized, tend to reduce seriously the limiting value for collapse; transverse bulkheads will, of course, have the contrary effect. In way of a lapped

* Morley and Bisacre, "Engineering," Vol. cvi, pages 99 and 129.

† Fairbairn's Experiments, *circa* 1860.

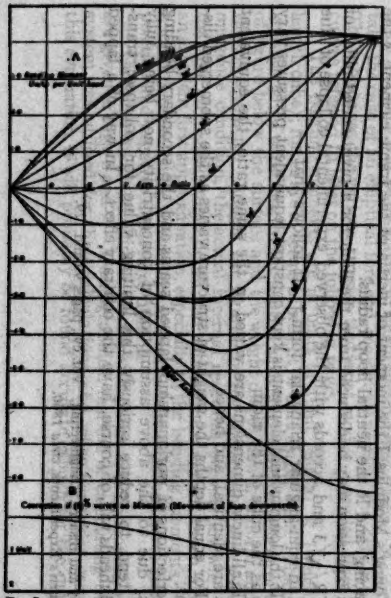


Fig. 5.—Bending Moment Cross Curves. Elliptical Neutral Hoop of Uniform Scantling.

Major Axis, 10 Length Units.

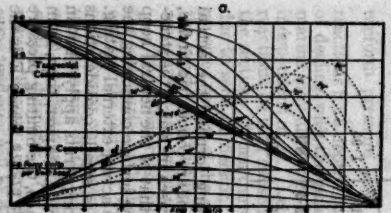


Fig. 6.—Thrust Cross Curves (as A, *Fig 5*)

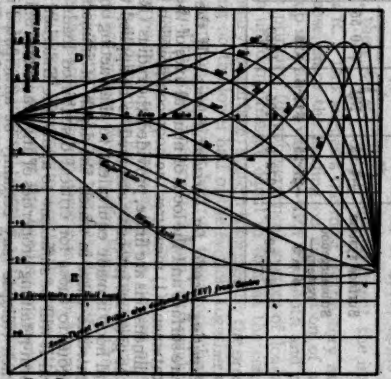


Fig. 7.—Filled on Minor Axis, Other Conditions (as A *Fig 6*)

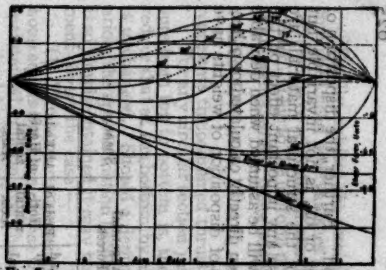


Fig. 8.—Surface System Elliptical Hoop. Bending Moment Cross Curves for Major Axis Vertical. Length, 10 Units.

Note.—Direct thrust or tension on hoop at ends of major axis is —
± (12·5 − shear at minor axis)

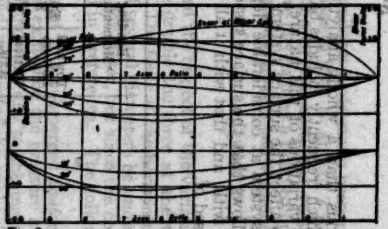


Fig. 9.—Surface System: Elliptical Hoop. Bending Moment Cross Curves for Major Axis Horizontal. Length, 10 Units.

Note.—Direct thrust or tension on hoop at ends of minor axis is —
± (12·5 × axes ratio squared + shear at major axis).

seam (or of a butted seam if the strap relieves the faying edges of pressure), the line of thrust does not coincide with the neutral axis of the section. If this intercept is z a moment $p \,.\, R\, s\, z$ must be borne by the structure. The compressive stress on the flange of the frame remote from the landing is increased and the depth at which an assigned stress f will be reached is given by $p = f\,A \,.\, I/R\, s\,(A\, z\, y + I)$, where A is the area and y the furthest fiber distance of the frame element. Written in this form the ratio of $A\, z\, y$ to I measures the importance of the effect of the lap. Should the plating be worked as in and out strakes of breadth b the effect is greater, but will not exceed the stress arising in an eccentrically loaded strut, viz.:—

$$f > \frac{p\,R\,s}{A}\left(1 + \frac{A\,z\,y}{I}\,\text{secant}\,\frac{b}{2}\sqrt{\frac{p\,R\,s}{E\,I}}\right)^{*}$$

Different sets of values apply, relating to an in or an out strake respectively For the value of R see the paragraph below.

Non-uniform Circular Sections.—The common case of a circular pressure surface combined with framing or floors so placed that the neutral hoop is not a concentric circle may be dealt with as follows (Letters *b*, *c*, *d*, Fig. 12):—

Replace the continuous loading on the pressure surface by a number of equal and equally-spaced forces each directed towards the center. Such a system of applied forces gives rise to a funicular regular polygon, inscribable in a circle. The sides of the funicular represent a series of internal reactions which, provided the center of the polygon coincides with the center of the applied forces, would maintain equilibrium. Making the number of forces very great, the system of reactions takes the form of a circular hoop, with uniform thrust at every point, but of unknown radius. This concept is similar to the linear arch of a bridge, and may be aptly termed the linear hoop. The radius k of the linear hoop is determined by stating the condition of no total change of curvature in the entire neutral hoop. Stating the moment at each point as equal to the thrust, multiplied by distance of line of thrust from neutral hoop, we have M = thrust $\times (r - \kappa)$, where r is the polar distance of the neutral hoop. The curvature is given by $e\,M$, e (the flexibility) being the inverse of EI, and

$$\int e\,M\,d\,s = 0. = \text{Thrust} \times \int e\,(r - \kappa)\,d\,s$$

$$\therefore\ \kappa \int e\,d\,s = \int e\,r\,d\,s$$

and

$$\kappa = \int e\,r\,d\,s \,/ \int e\,d\,s$$

The linear hoop is, therefore, the circle concentric with the pressure surface and of radius equal to the mean distance of the neutral hoop, "weighted," or given a line density varying as the flexibilities.

The general correctness of this result is also apparent if, in the sketch (Fig. 3), hinged joints are supposed to exist at A and B. A tangential reaction occurs at each of the points, and the pressure on ACB is supported by a simple uniform thrust at every point. The portion ADB carries its loading as a beam with poly-directional loading, the supporting points being A and B. The tangents at the beam ends change direction as the load is applied, but those at the hoop ends do not. Solidifying the joints at A and B, a bending moment must be set up at each end of the frame ACB to make the tangents above A and B coincide with those below. The upper frame is then in a condition of a plain beam, loaded at its extremities and supported symmetrically; that is to say, a bending moment of constant value is set up over ACB.

*Morley, "Theory of Structures," page 293.

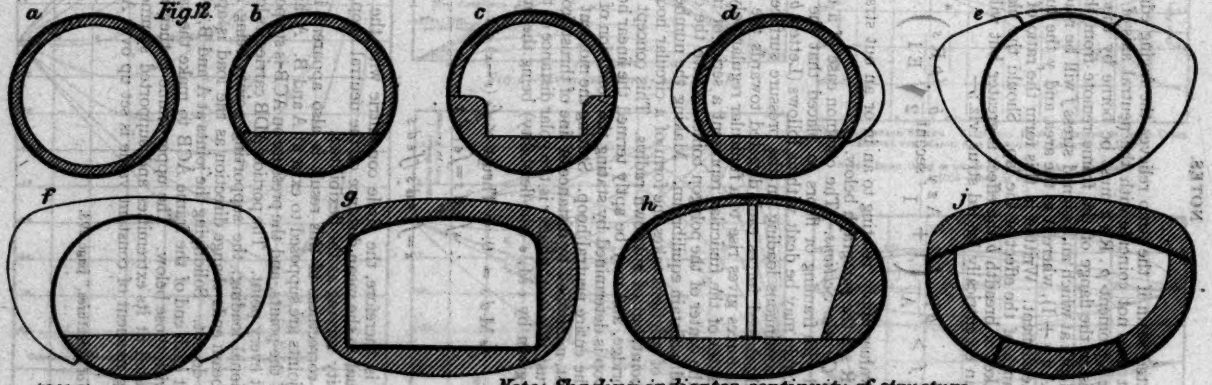


Fig 12.

Note:- Shading indicates continuity of structure.

From this analysis one may conclude:—

(5) Local variation of the construction of the frame is highly undesirable, as it induces bending moment in addition to the existing thrust.

(6) A variation should be as solid as possible (*e.g.*, *b* is preferable to *c*, Fig. 12).

(7) The introduction of a knee attachment at the departure points has a further detrimental effect on the weakest portion.

Further, the frame proper is in the condition of an eccentrically loaded strut and the formula already given for the effect of in and out plating applies, but with the substitution of $\frac{\pi R}{2\sqrt{3}}$ for $b/2$.

Non-uniform Non-circular Sections.—The general case of non-circular forms may be dealt with by similar analysis, provided the applied pressures (considered as forces transferred to the neutral hoop) preserve uniform distribution. (See Appendix for a further consideration of this point.) The pressure surface being given, the force hoop (the force polygon in its limiting form) is uniquely determined. Equally, the corresponding family of funicular hoops is determined, and the problem consists in selecting the appropriate funicular to suit the known structural formation. The steps in the process are as follows:—

(*a*) Find the centroid and principal axis of the "weighted" neutral hoop (*i.e.*, carrying a line density varying as the flexibilities).

(*b*) Calculate the center of zero total deformation, viz.:—

$$X = \int \epsilon r^2 x \, ds \,/\, 2 \int \epsilon x^2 \, ds$$

$$Y = \int \epsilon r^2 y \, ds \,/\, 2 \int \epsilon y^2 \, ds,$$

where x, y and r refer to the co-ordinates and polar distances of the elements of length measured from the centroid.

(*c*) Calculate the radius K of gyration about (X, Y) of the "weighted" hoop. Then the linear hoop lies midway between the neutral hoop and its reciprocal figure with respect to (X, Y) and K; this reduces to

(8) The hoop thrust everywhere equals $p r_1$, where r_1 refers to the distance of the point from (X, Y), and acts normally to the direction of r_1.

(9) The bending moment everywhere equals $(K^2 - r^2)\frac{p}{2}$.

Elliptical Forms.—Most forms in actual use are bisymmetrical and the point (X, Y) coincides with the geometrical center. In all cases uni-symmetry exists and only X or Y has to be found (excepting where a pillar is employed). Cross curves for all elliptical forms, derived from these results, are given in Figs. 5 to 7, and furnish data for the complete evaluation of the stresses at all points. In Fig. 4 the actual diagram for a particular case is drawn down. Letter A in Fig. 5 (in the series of cross curves) relates to bending moments, and Fig. 6 to tangential and normal forces acting on the cross-sections of a uniform frame. If the scantling of the elliptical frame is varied to suit the distribution of moment the result (9) above shows that all moments will undergo an equal (algebraical) increase. The extreme and hypothetical case is when the strength modulus is varied at every point as the primary moment; the extreme correction is obtained, therefore, from the curve (Letter B) in the lower part of Fig. 5. The direct and shear forces are unaltered.

Fig. 7 represents a family of cross curves for the case in which a pillar is fitted on the minor axis, deduced on similar lines by use of the following artifice:—Considering one-half of the ellipse only, replace the pillar by a side of

infinite strength. The flexibility becomes zero, and the centroid and value of X are calculated on that assumption. Certain bending moments arise in the imaginary side, but, when the second half is similarly treated and placed in juxtaposition, these moments mutually cancel, leaving a thrust only in the side, which may now be reconverted to a pillar. A curve showing these thrusts is included (Letter E in lower part of Fig. 7).

The advantage of applying the foregoing theory where applicable is that the relative effect of variations in the design can be readily predicted: as compared with Dr. Bruhn's more general method (see Transactions, Institution of Naval Architects, 1901 and 1904), based on the theory of least work, the processes are visible and the actual calculations less intricate and more accurate. The same remark applies to the comparison with Professor Hovgaard's* analysis based on the principle of continuity.

The following deductions may be drawn for the general case:—

(10) Points of zero bending moment are defined by the intersections of the circle of deformation (radius K) and the neutral hoop (Fig. 4).

(11) Maximum moments occur where the normals to this circle and the hoop are co-incident.

(12) The moment causes flexure inwards where the neutral hoop lies within the circle of deformation and *vice versa* (Fig. 4).

(13) For all bi-symmetrical cases any variation of scantling causes a movement of the base of the moments, parallel to itself, and so as to increase the moments in the strengthened vicinity (that is, increased strength attracts increased stress).

(14) If part of the structure is of very great rigidity compared to the remainder, the precise disposition of the neutral axes in that part is of small consequence.

(15) A local discontinuity (*e.g.*, a lapped seam, butt strap of a frame, swelling for a fitting, &c.) scarcely affects the general distribution of bending moment. The relation of the linear hoop to the neutral axis of the discontinuity determines the local value of the moment.

(16) The circle of deformation forms a first approximation to the linear hoop.

Typical sections in which some of these effects may be traced are given in Letters *a* to *j*, Fig. 12. Ambiguity exists in such cases as *e* and *f*, where a circular pressure hull has a light but deep plate connection to an external hull. Were there no riveted connection, this framing would serve to prevent deformation (under the critical pressure) of the circular hull, in which a simple hoop compression would exist. Were the connection perfect, as for an electrically welded job, bending moment would be induced at every point, as determined by the previous results. The extent to which the customary open pitched riveting effects the same result is doubtful, and I believe important builders ignore any value the connection may have.

In conclusion I have to acknowledge my indebtedness to Miss Madeline Whiting who carried out some of the detail calculations for the principal cross curves and to Sir W. G. Armstrong Whitworth and Co., for permission to put forward this paper.

APPENDIX.

1. NOTE ON THE LONGITUDINAL FORCES.

In the longitudinal direction every section supports the sum of the axial components of the hydrostatic pressures up to that section. For the submerged system the resultant is p A and acts through the centroid of the section. Obviously the transverse framing plays no part in resisting these forces. In cylinders devoid of transverse framing (*e.g.* boilers) the longitudinal stress is one-half

*See Hovgaard's "Structural Design of Warships," page 68. It is to be noted that the numerical example given appears to be in error, as the reactions are assumed as equal.

the transverse, but in submarines the proportion varies with the proportion of plating to framing. It may reach or exceed unity. The center of action is never far removed from the center of resistance, and hence no appreciable bending moments arise. The shell plating is subjected to comparatively equal stresses, acting in orthogonal planes. The interaction is obscure, as various aspects of stress-strain theory give different results. The effect may be ignored, save that in elliptical sections shearing stresses of $\frac{1}{2}(f_1+f_1)$ are set up in the 45 degree helices.

The corresponding surface system for a cylinder is interesting. The total forces on the upper and lower semicircles are $\mp R^2/3$. Each acts $3\pi R/16$ from the axis and a longitudinal moment $\pi R^4/8$ arises. The moment of inertia of the shell is about $2\pi R^3 t$ and a stress $\mp R^3/16\,t$ results. This value is in terms of the weight of the unit cube of water, and is very small.

2. PROOF OF NON-EXISTENCE OF BENDING MOMENT IN A SEMICIRCULAR SHELL JUST BUOYANT.

Let Fig. 10 represent the quadrantal section of a right circular cylinder, immersed in a liquid with the horizontal diameter in the surface, and of unit length perpendicular to the paper. Let the weight of the mass forming the boundary BOC equal the displacement. Let R be the radius and let ω be the weight of unit length of arc. Then

$$\pi R\,\omega/2=\pi R^2/4 \text{ and } \omega=R/2.$$

The internal moment experienced at any point O is the sum of the moments about that point of the forces acting on each element of the segment BO. Consider an element at P, subtending an angle $\delta\phi$ at the center.

Weight acting downwards is $R\,\delta\phi\,.\,R/2$. Pressure normally is $(P\,p)\,R\,\delta\phi$. Moments about O are $\frac{R^2\,\delta\phi}{2}$ (P q − O t) and $-R\,\delta\phi\,.\,P\,p\times O\,s$.

The sum of these may be written—

$$\frac{R^2\,\delta\phi}{2}(R\cos\phi-R\cos\alpha)-R\,\delta\phi\,.\,R\sin\phi\,.\,R\sin(\alpha-\phi)$$

The element of moment is, therefore,

$$\frac{R^3}{2}\Big\{(\cos\phi-\cos\alpha)\,d\phi-2\sin\phi\sin(\alpha-\phi)\,d\phi.\Big\}$$

Writing M for the total moment of all forces above O about the point O,

$$\frac{2M}{R^3}=\int_0^\alpha(\cos\phi-\cos\alpha)\,d\phi-2\int_0^\alpha\sin\phi\sin(\alpha-\phi)\,d\phi$$

$$=\Big[\sin\phi\Big]_0^\alpha-\cos\alpha\,.\,\alpha-2\sin\alpha\int_0^\alpha\sin\phi\cos\phi\,d\phi+2\cos\alpha\int_0^\alpha\sin^2\phi\,d\phi$$

$$=\sin\alpha-\alpha\cos\alpha-\sin\alpha\int_0^\alpha\sin 2\phi\,.\,d\phi+2\cos\alpha\left[\frac{\phi-\sin\phi\cos\phi}{2}\right]_0^\alpha$$

$$=\sin\alpha-\alpha\cos\alpha-\sin\alpha\left[-\tfrac{1}{2}\cos 2\phi\right]_0^\alpha+\cos\alpha(\alpha-\sin\alpha\cos\alpha)$$

$$=\sin\alpha-\sin\alpha\cos^2\alpha+\tfrac{1}{2}\sin\alpha(\cos 2\alpha-1)$$

$$=\sin\alpha-\sin\alpha\cos^2\alpha+\tfrac{1}{2}\sin\alpha(2\cos^2\alpha-2)=0.$$

and consequently no bending moment occurs at any point of the arc. Also the

vertical element of the forces on P is $\frac{R^2}{2}\delta\phi - R^2\sin^2\phi\,\delta\phi$, and the horizontal element of the forces on P is $R^2\sin\phi\cos\phi\,\delta\phi$.

Integrating from B to O—

$$V = \frac{R^2\alpha}{2} - R^2\int_0^\alpha \sin^2\phi\,d\phi \qquad H = \frac{R^2}{2}\int_0^\alpha \sin 2\phi\,d\phi$$

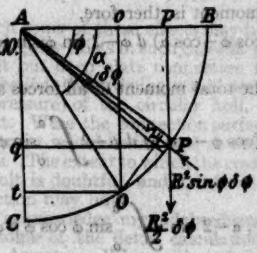
$$= \frac{R^2\alpha}{2} - R^2\left(\frac{\alpha}{2} - \frac{\sin\alpha\cos\alpha}{2}\right) \qquad = -\frac{R^2}{4}(\cos 2\alpha - 1)$$

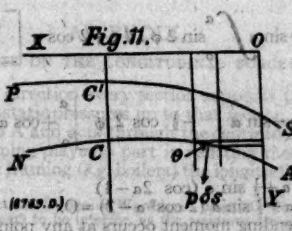
$$= \frac{R^2}{2}.\sin\alpha\cos\alpha \qquad = \frac{R^2}{2}\sin^2\alpha.$$

Hence $\frac{H}{V} = \frac{\sin^2\alpha}{\sin\alpha\cos\alpha} = \tan\alpha$, *i.e.*, the resultant is tangential at O. The resultant force or hoop compression at O is $\frac{R^2}{2}\sin\alpha$, and this vanishes at B and becomes $\frac{R^2}{2}$ at C.

3. NOTE ON THE PRESSURE UNIFORMITY REQUIREMENT REFERRED TO IN PAPER.

Unfortunately, the ideal case never arises, except in circular forms. Even if the structural member is of uniform scantling the axes ratio of the neutral axes $(a-z : b-z)$ is not equal to that of the pressure surface $(a : b)$. Moreover, in general some floor plate or equivalent is introduced in the locality of a maximum moment.





(8743.5.)

Let the arc PS (Fig. 11) represent part of the pressure surface, and NA part of the neutral axis. Imagine a fictitious pressure surface capable of being introduced along NA. Let the normal at C define a frame of reference OXY. The force on any element δs of NA is $p\,\delta s$, and when resolved normal to OX and to OY furnishes components $p \cdot \delta s \cos\theta$ and $p \cdot \delta s \sin\theta$. The projections of the element δs on these axes are $\delta s \cos\theta$ and $\delta s \sin\theta$. Hence the intensity of the resolved forces on the reference frame is uniformly p, with a range defined by the perpendicular tangent to the curve. The pressure forces actually acting on PS when resolved similarly also give rise to uniform pressure intensity p on the reference frame. The pressure surface assumed is, therefore, a matter of importance only inasmuch as the ranges on the reference frame are different. Accordingly at C the stress difference as between PS or NA being the pressure surface is that due to the pressure p acting uniformly across CC^1.

The change in bending moment is approximately $\frac{p}{2} \times (C\,C')^2$. If a pressure surface parallel to the shell but at a mean polar distance equal to that of the neutral axis be utilized, the approximation is very close. The value of the pressure intensity must be adjusted in harmony. An immediate corollary applies to the change of stress due to flooding an internal pressure ballast tank.

4. NOTE ON THE CROSS CURVES.

These are calculated for a major axis of length 10 units and for minor axes of all less amounts. For other lengths of axis the bending moments vary as the square of the length ratio for the submergence diagrams, and as the cube for the surface diagrams. The moments are in terms of (unit cube × unit length) when unit pressure per unit area or per unit length of girth for the longitudinal element is applied. Bending moments have been considered positive when they cause inward flexure, *i.e.*, when they increase the shell compression of an internally-framed vessel. When the major and minor axes are nearly equal it is convenient to use the following equation:—

Bending moment $= a\,(a - b)\,s\,p \times C$, s being the frame spacing and C a coefficient.

Radial position	Minor axis	10°	20°	30°	40°
Value of C	0.47	0.44	0.37	0.25	0.10
Radial position	50°	60°	70°	80°	Major axis
Value of C	−0.06	−0.21	−0.35	−0.45	−0.48

The effect of errors of workmanship in circular-hulled boats is ascertainable from this equation.—"Engineering," May 27, 1921.

NAVAL GUNNERY AND CONSTRUCTION.

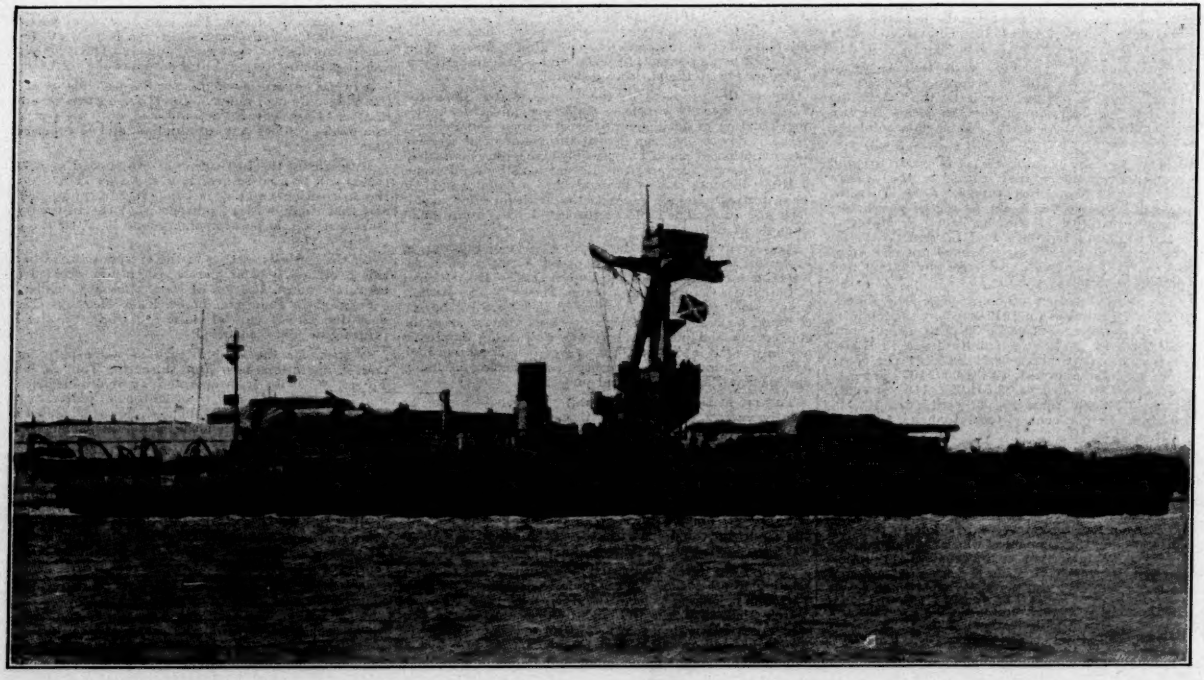
The gunnery experiments which were carried out in the Channel early in February, and which resulted in the sinking of the ex-German battleship *Baden*, appear to have had a wider significance than was appreciated at the time. They were supposed to have been held mainly to determine the resistance of German armor and internal protection to the attack of heavy naval projectiles. No official account of the firing has been published, but we gather from unofficial reports that the bombardment was performed by the monitor *Lord Clive*, which had been temporarily armed with three heavy guns—of 15-inch or larger caliber—on a triple mounting, to which we shall revert later. The distance between firing ship and target was not great, but the guns were fired with reduced charges, which gave the projectiles a velocity equivalent to that which would remain to them at very long range. The fact that certain German ships of older design and less substantial protection had endured at the Battle of Jutland a tremendous amount of punishment without being sunk or absolutely disabled

seemed to warrant the assumption that the *Baden* would survive a very severe hammering. This expectation was not fulfilled. So far as we are able to gather, her flotation was destroyed long before the prescribed number of rounds had been fired, either because our projectiles were exceptionally destructive or because the armor and other defenses of the ship were less robust than had been surmised. As originally planned, the tests, we believe, were to have included an attack by torpedo-carrying aircraft, though considering that the target was stationary, the practical value of the latter experiment cannot have been great. Even when allowance is made for the difficulty of obtaining a straight run from torpedoes which have been dropped into the sea from aircraft flying, perhaps, 50 feet above the surface at a speed of 70 to 90 miles an hour, it should not be hard to strike a motionless target with an overall length of nearly 590 feet. These torpedo attacks were duly delivered, but it is stated that the *Baden* had already been sunk by gunfire and was lying in shallow water, with a heavy list to starboard, when struck by the torpedoes. Our illustration shows the damaged ship lying partially submerged between Dean Tail and Dean Elbow buoys, between the mainland and the Isle of Wight. She has since been salved and patched up for further experiments.

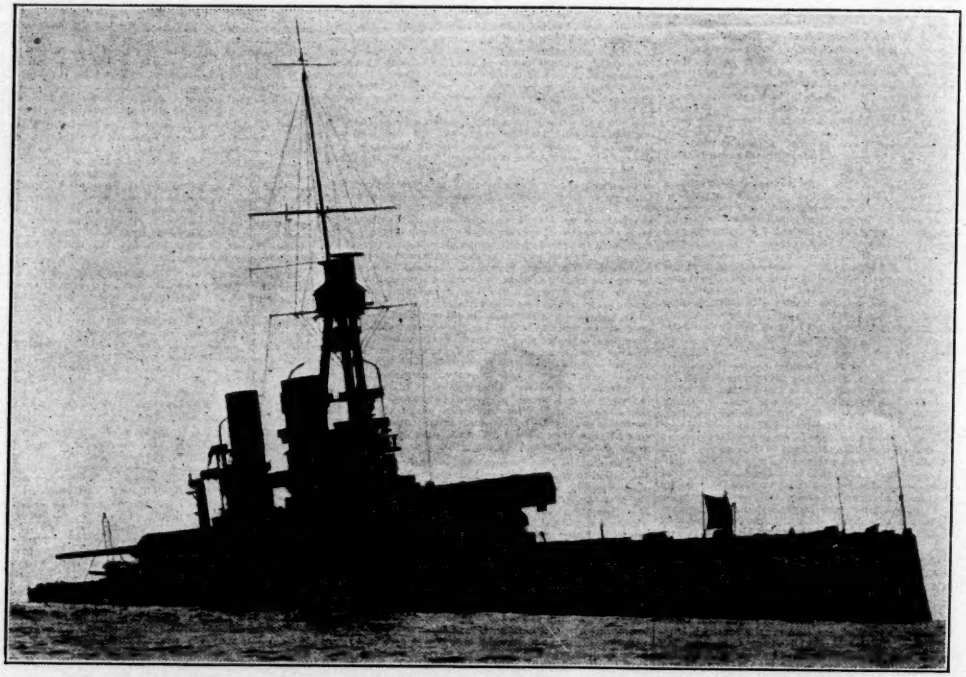
In the absence of data as to the type of gun used in the attack, the number and character of the projectiles fired, their initial velocity, and the general conditions in which the firing took place, it would be futile to attempt any definite inferences from this most interesting gunnery experiment. Sir E. T. d'Eyncourt has stated, however, that the *Baden's* thickest armor failed under an attack which British-made plates of the same thickness would have resisted. It is certainly gratifying to have this authoritative tribute to the excellence of British armor. Sir Eustace d'Eyncourt's statement corroborates the remarks made by Sir Robert Hadfield at Sheffield last month, which we reproduced in our issue of April 1st. His claim was that at Jutland our armor withstood the attacks which it was designed to defeat, and kept out the German projectiles wherever its thickness warranted that expectation. He attributed the failure of the *Queen Mary's* 9-inch turret armor to the concentrated effect of two and probably three armor-piercing shell, a blow approximating to 48,000 foot-tons. On the other hand, as the protographs published in "The Engineer" of February 20th, 1920, clearly showed, the 11-inch and 12-inch belt and barbette armor of the German battle-cruisers was holed repeatedly by our projectiles. In the course of the tests made with the *Baden* last February her water-line belt, nearly 14 inches thick, was penetrated time after time, although, as we have said, the velocity of the projectiles had been reduced to correspond with firing at considerable range.

To illustrate the formidable nature of the target attacked we may quote from Mr. S. V. Goodall's description of the *Baden's* armor and protective plating, given in his recent paper read before the Institution of Naval Architects. The main belt, he stated, is 13¾ inches thick, tapering to 6 11/16 inches at the lower edge; above this is a 9¾-inch belt extending to the upper deck. This citadel is enclosed by athwartship armor bulkheads, and beyond them thinner side armor is fitted which terminates at armor bulkheads. Above the upper deck and set in about 5 feet from the deck edge is the 6 11/16-inch armor of the secondary battery. The gap so formed is protected by 1 3/16-inch deck plating. The deck above this battery is from 1 3/16 inches to 1 9/16 inches thick. The sloping protective deck—the middle deck amidships and aft—is 1 3/16 inches thick; abaft the citadel this deck is increased in thickness up to a maximum of 4¾ inches over the steering gear. Forward of the citadel the protective deck —the lower deck—is generally 2¾ inches thick. Barbette protection varies

THE EXPERIMENTAL BOMBARDMENT OF A GERMAN BATTLESHIP.



THE BRITISH MONITOR "LORD CLIVE" FITTED WITH EXPERIMENTAL TRIPLE BIG GUN MOUNTING.



THE GERMAN BATTLESHIP "BADEN" AFTER BEING ATTACKED BY GUNFIRE AND TORPEDOES.

from 13¾-inch armor above the top decks to 1-inch plating at the bases of A and B turrets, and 4½-inch armor at the bases of X and Y turrets. Gun-house armor is 13¾ inches thick at the front, 9⅞ inches at the sides, horizontal roof 3 15/16 inches thick, and sloping roof 4¾ inches. The 5.9-inch casemates of the secondary battery are formed by transverse and longitudinal bulkheads of ⅞-inch plating. The fore conning-tower has a maximum thickness of 13¾ inches with a 5⅞-inch roof, the corresponding thicknesses for the after conning tower being 7⅛ inches and 5¼ inches, respectively. Above the protective deck the coal bunkers extend practically from A to Y barbettes, and when filled with coal reinforce the protection afforded by belt and decks. A further addition to this protection is provided by the 1 3/16-inch splinter bulkhead, which is a continuation to the upper deck of the torpedo protection bulkhead. Armor gratings protecting the openings in the forecastle and protective decks are of the built-up type formed by ½-inch bars. In some of the protective deck openings a second tier of gratings with bars fore and aft is fitted immediately below the upper tier. As regards protection against torpedoes, a longitudinal bulkhead 2 inches thick, terminating on 1 3/16-inch transverse bulkheads, is fitted throughout the greater part of the length of the ship. Outside this are coal bunkers about 6 feet wide, and beyond these an air space 7 feet wide amidships and slightly less at the ends.

Whatever the shortcomings of our pre-Jutland armor-piercing projectiles may have been—and the defects attributed to them by Lord Jellicoe have been vigorously challenged by high authorities—there is not any doubt that the armor-piercing shells now used in the Royal Navy are of a most efficient type. The modifications introduced after Jutland concerned not merely the filling and the fuse, but a revision of the old proof requirements for armor-piercing shell bodies, which had become out of date. We have been assured by a leading artillery expert that the modified type of 13.5-inch armor-piercing shell now in use has greater penetrative power at a given range than the 15-inch armor-piercing shell fired at Jutland, and is therefore the more destructive weapon of the two, notwithstanding that it weighs only 1,400 pounds as against 1,930 pounds. As the improvement extends to armor-piercing projectiles of all calibers, it goes without saying that the armament of our present-day battle fleet is incomparably more formidable than was the case a few years ago, though the ships remain the same. Before leaving this subject a word may be said about the German projectiles. It had been assumed that Germany had adopted very long shell for her heavy naval guns, but this opinion turns out to be incorrect, at least as regards the 15-inch gun. The pieces of this caliber in the *Baden* employed an armor-piercing shell 3.5 calibers long and a high-explosive shell 4.1 calibers long, the weight in both cases being 1,653 pounds, of which the armor-piercing burster represented 51.9 pounds and the high-explosive burster 148 pounds. The German 15-inch projectile was thus nearly 300 pounds lighter than the British, and its length did not exceed that of the latter. On the other hand, the German 11-inch and 12-inch high-explosive shell had a length of approximately 4½ calibers. The principle of using very long projectiles is not by any means of recent date, for as far back as 1871 we find Sir Joseph Whitworth writing as follows:—"I desire to make all guns capable of firing powerful shells six diameters long, using the regular charge of powder. When high velocity is required, and for long ranges, then projectiles should be from three to four diameters long." It does not appear that shell of six diameters in length have ever been fired in actual warfare, though the 12-inch high-explosive "portmanteaux," loaded with "Shimose," with which the Japanese attacked the Russian ships at Tsushima, are said to have been over 5 feet

long. They tumbled badly in flight, but despite this a remarkably high percentage of hits was made, and the heavy burster caused great havoc.

Gunnery practice against ship targets has not hitherto been indulged in by the British Navy to the same extent as in foreign navies, nor when such tests were made have they invariably been rendered as instructive as they might have been. On such occasions it has been customary to select some obsolete ship and subject it to bombardment by modern ordnance without attempting to reproduce in the target the defensive qualities that would be encountered in modern armored ships. Generally, therefore, the result has been to convey an exaggerated impression of the destructive powers of the projectiles employed. This undoubtedly occurred in the cases of the *Belleisle*, *Edinburgh*, and *Hero* experiments. In Germany, France, and the United States a more practical value was often given to such tests by reconstructing the target to resemble in part a modern ship. Germany led the way in this direction, spending large sums yearly on the fitting out of target ships, whole squadrons of which were sometimes attacked simultaneously. The most fruitful American trial was that to which the *San Marcos*—ex *Texas*—was subjected in March, 1911, for the result brought about a revolution in American ideas of armor protection and led to the abandonment of armor on the top-sides and its concentration on the water line, gun positions, and other vital parts. When all is said and done, however, peace experiments can never be as instructive as actual war experience. It is probable that our naval officers and constructors derived more useful information from Jutland and the Dogger Bank than they could have obtained from years of ceaseless peace experiment on a lavish scale. Whatever the object of attacking the *Baden* may have been, it was certainly not to stage a mere pyrotechnical display. The Admiralty may have desired to test the present type of armor-piercing shell against the thickest armor of a modern ship, to determine some unsolved question of protection, or, perhaps, to try a new piece of naval ordnance in contemplation for the battleships of the current program.

The fact that a triple mounting for heavy guns was used in the experiment is very suggestive, and while there is no definite evidence that this system of mounting is to be adopted in the new battleships, the indications certainly point that way. In common with many other innovations in naval design, we owe this system to the Italians, who first introduced it in the *Dante Alighieri*, laid down in 1909. By taking the bold step of disposing the main armament in triple turrets, the late Colonel Cuniberti was able to mount a battery of twelve 12-inch guns, associated with a powerful quick-firing armament, in a ship of only 19,500 tons, well protected over the vitals, with an adequate coal capacity, and possessing the remarkable speed of 23 knots. Had the conventional twin mounting been retained, it would not, he estimated, have been possible to arm the ship with more than ten 12-inch guns, and even then less weight and space would have been left over for protection, machinery, &c. So substantial a gain went far to offset the objections—real or imaginary—which had previously militated against the grouping of more than two heavy guns in one position. In the same year the triple turret was adopted by Russia for the four battleships of the "*Gangut*" class, in the designing of which Colonel Cuniberti had a large share; and in 1910 Austria followed suit by laying down the *Viribus Unitis*, whose twelve 12-inch guns were on triple mountings. Reports of the gunnery trials of the *Dante Alighieri* and *Viribus Unitis* were conflicting, some accounts stating that the complicated mechanism had proved fatal to rapid fire and that the deflection caused by the discharge of the side guns made accurate practice impossible. On the other hand, the Italian authorities professed themselves perfectly satisfied with the

triple turret, which, they declared, was as simple to manipulate and as accurate in fire as the twin mounting. Meanwhile experiments were in progress across the Atlantic, and in 1912 it was announced that the two battleships to be laid down that year, the *Oklahoma* and *Nevada*, would have part of the main armament disposed in three-gun turrets. That these must have proved satisfactory is evident from the circumstance that all the American battleships built subsequently, excepting only the four "*Marylands*," have their main armament mounted on the same principle. Both the deflection trouble and the tendency, when the three guns are fired simultaneously, of mutual "air wave" interference to prejudice the accurate flight of the projectiles, are said to have been overcome by discharging the right and left-hand guns together and the middle gun a fraction of a second later, the necessary interval being secured by a special device. In the earlier American mountings of this pattern the three guns were apparently mounted on a common slide and could not be elevated or depressed independently of one another; the installation, therefore, was to all intents a three-barrelled gun. But in later ships this principle appears to have been discarded, for a photograph of the battleship *Tennessee*, published in "The Engineer" of May 21st, 1920, distinctly showed the three 14-inch guns in each of the forward turrets at varying angles of elevation.

Turning to the question of weight, it would appear that while the Italians employed most of the weight saved by concentrating twelve guns on four mountings instead of six in increasing the power of the machinery, the Americans have preferred to utilize the margin in reinforcing the armor on the gun positions, with the result that the gross weight of two triple turrets is little, if at all, below that of three twin turrets less stoutly armored. We draw this conclusion from official American figures, according to which the weight of a 14-inch turret, containing three 14-inch 50-caliber guns, is "not far from 2,500 tons, of which total, of course, the armor is the greater part." Since the weight of a British pattern turret, containing two 15-inch 45-caliber guns, with their ammunition and accessories, is understood not to exceed 1,350 tons, it would seem that the weight of six American 14-inch 50-caliber guns, triple mounted, is greatly in excess of that of six British 15-inch 45-caliber guns mounted in pairs, the figures being 5,000 and 4,050 tons, respectively. The disparity is so great that we assume that some item or items of weight not included in the British total are contained in the American figure. Hitherto the triple mounting has been looked at askance by British naval opinion, but it may well be that the necessity of endowing our new ships with increased gun power without unduly magnifying dimensions has forced the Admiralty to accept a system which it does not view with entire favor. In that case its attitude is on a par with that of Rear Admiral Twining, U.S.N., Chief of the Bureau of Ordnance, who in 1912 expressed a dislike for the triple turret, but nevertheless recommended it as the only method by which the weight needed for additional protection could be saved. Although the triple turret has not yet been fitted in a British ship, 12-inch mountings of this description are believed to have been manufactured by Armstrong, Whitworth and Co. for the Italian Government, and a description of one such mounting, designed at Elswick, was published in 1913. In this case the guns were independently elevated and depressed by hydraulic power, controlled by valves in the sighting position.

Provided that accuracy of fire and facility of working the guns are not unduly prejudiced thereby, the adoption of triple turrets for our new ships, if resolved upon, must be considered a wise step. Having decided to resume capital ship construction after a pause of five years, we find that other Powers are completing and building ships which in armament

and speed will far surpass the finest vessels we now possess. Our designers must therefore cast about for some expedient which will enable them to produce a new type, approximately equal in battle power to the best ships in other navies, without putting an intolerable strain on the national purse. It would be easy enough to recover our place at a bound by laying down ships of unheard-of dimensions and cost, but there are weighty reasons against such a policy. The solution must consequently be sought, not in mere size, but in technical modifications, such as a greater concentration of armament, new methods of protection, and weight-saving principles in the machinery department. If our designers and marine engineers are put upon their mettle they will, we feel confident, evolve a type of warship which need fear no comparison with foreign contemporaries of equal or greater displacement and cost. The most powerful battleship now under construction is the United States "*Indiana*" type, which displaces 43,200 tons and is armed with twelve 16-inch 50-caliber guns, the speed being 23 knots. It does not follow that the Admiralty will deem it prudent to put so many eggs into one basket, nor is it certain that 23-knot battleships would be the most suitable investment for the British Navy. By contenting ourselves with a battery of ten 15-inch or 16-inch guns, in four turrets, with adequate but not exaggerated protection against gunfire and submerged attack, machinery and boilers designed to generate the maximum power for their weight, and—last but not least—by thoroughly reviewing the existing standards of stress to determine the feasibility of accepting lighter scantlings, we may arrive at a type of ship which, if inferior in displacement and cost to the heaviest vessels building elsewhere, will yet be admirably suited to the requirements of the naval defense of the Empire.—"The Engineer," April 22, 1921.

THE USE OF GAS AND OTHER SPECIAL SHELL IN NAVAL WARFARE.

A critical examination of the possibilities of application of gas to naval warfare. It is not only probable, but certain, that the crew on board a vessel would not have any less objection to don masks than troops in the open, owing to the restricted space on board with a high temperature, lack of ventilation and the freedom of movement necessarily inherent to the work they have to carry out, but owing to the special conditions obtaining on board ship, masks must be worn.

The experience of the war points to the desirability of the adoption of a single type of shell, armor-piercing, filled with high explosive. The question of combining with these shell a gas charge, might therefore be considered, especially as the small amount of gas necessary to secure effective gas effect on a ship favors this solution. Such a shell should be fitted with a delay-action fuze, to bring the gas into play.

A suitable gas for naval projectiles should have the following characteristics: Be of a single type and new composition; have small volume and a high degree of persistency; be irritating and poisonous; be difficult to dissolve in water or be neutralized. It should be stable, possibly solid, and become gaseous under the action of heat or the energy developed on detonation of a special explosive charge in the projectile. Its composition and method of employment should be kept a secret. (Capt. Silvio Salza, *Rivista Marittima*, April, 1921, 9 pp.)—"The Technical Review," June 14, 1921.

ASSOCIATION NOTES.

The editions of the February and May, 1921, numbers of the JOURNAL of the Society have been exhausted. In connection with any new applications during the present year, adjustment of accounts will be made accordingly.

The following new members and associates have joined the Society since the publication of the last JOURNAL:

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Thomas, A. C., Lieutenant, U. S. N.
Wirth, T. R., Ensign, U. S. N.
Wooster, S. H., Lieutenant, U. S. N.

ASSOCIATES.

Greaves, F. G., 1215 North 9th St., Tacoma, Wash.

Pearson, C. F., Planning Department, Navy Yard, Mare Island, Vallejo, Calif.

Stillman, T. B., care Babcock & Wilcox Co., 85 Liberty St., New York City.

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